PLATE TECTONICS

By Arthur H. Maybin, III
South Carolina Department of Natural Resources
Geological Survey

PLATE TECTONICS

- In geologic terms, a plate is a large slab of solid rock. The word tectonic comes from the Greek root “to build.” Combining the terms, ***plate tectonics*** refers to how Earth’s surface is built of plates.

PLATE TECTONICS THEORY

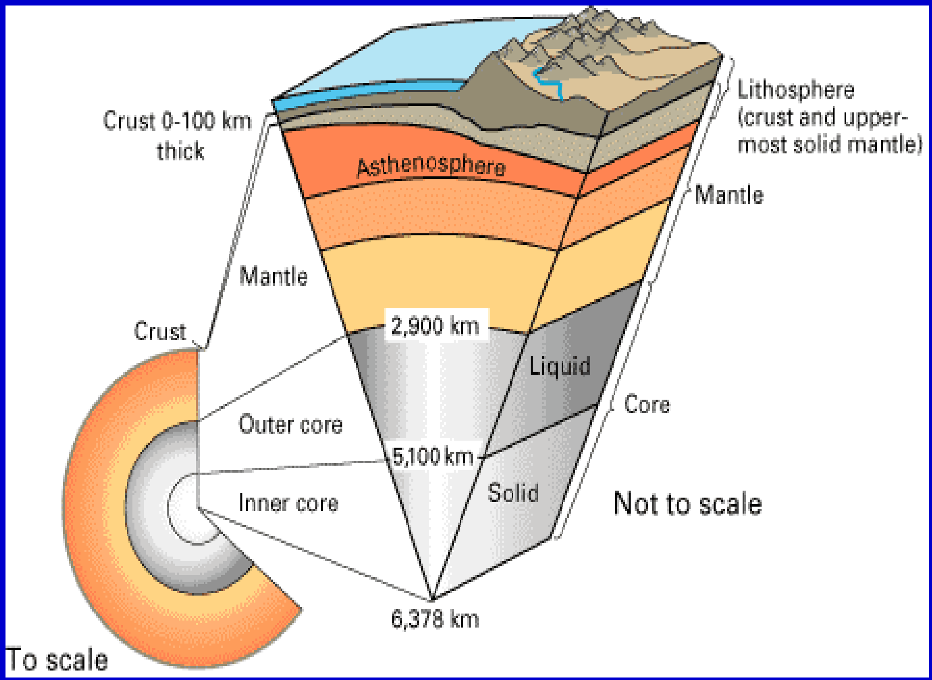
- Lithosphere (crust) is broken into a dozen or more large and small rigid plates.
- Plates move relative to one another above the asthenosphere (upper mantle).
- Many important geologic processes operate primarily at plate boundaries , e.g.... Volcanic activity, mountain building, earthquake activity.

PHYSICAL DIVISIONS OF THE EARTH'S INTERIOR

- CRUST
- MANTLE
  - LESS DENSE UPPER MANTLE
  - MORE DENSE LOWER MANTLE
- LIQUID OUTER CORE
- SOLID INNER CORE

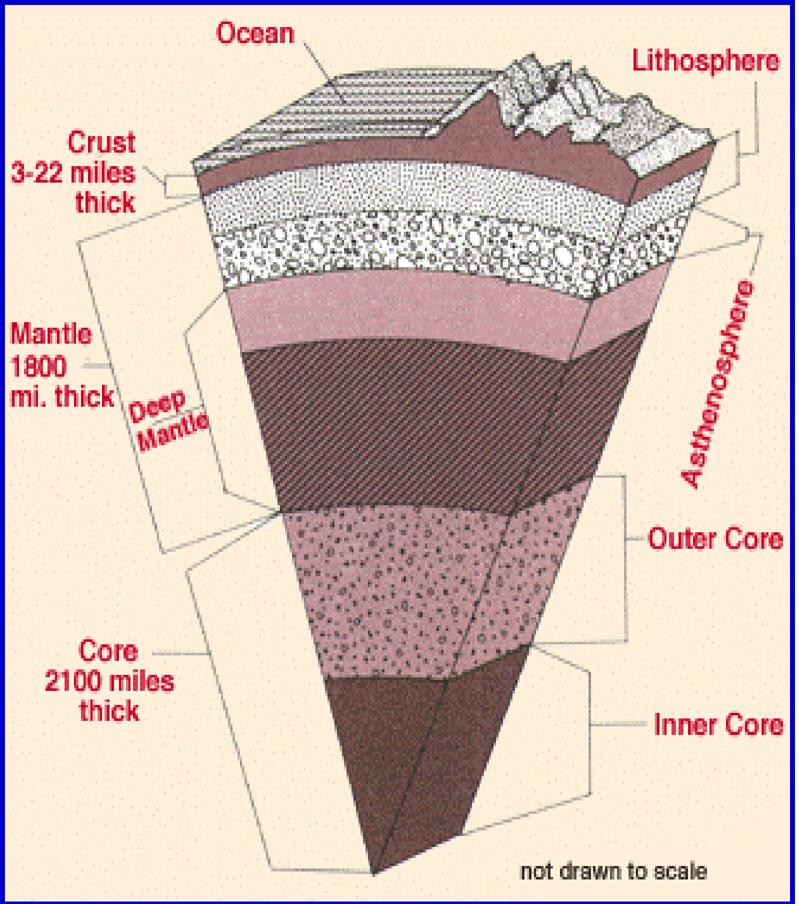
DIVISIONS OF THE EARTH'S INTERIOR

- CRUST (7-100 KM THICK) CONTAINS MINERALS WITH OXYGEN, SILICON, ALUMINUM, IRON, CALCIUM, SODIUM, POTASSIUM, MAGNESIUM
- MANTLE (ABOUT 2800 KM THICK) IRON MAGNESIUM SILICATE MINERALS
- CORE (ABOUT 3500 KM THICK) COMPOSED MOSTLY OF IRON, SOME NICKEL, SULFUR, OXYGEN



DIVISIONS OF THE UPPER MANTLE AND CRUST

- LITHOSPHERE-- outermost layer of rigid rock that includes the crust and upper mantle
  - OCEANIC CRUST-- found in ocean basins; thin and dense; contains much iron and magnesium
  - CONTINENTAL CRUST--found under continents; thicker and less dense than oceanic crust; contains less iron and magnesium and more aluminum, calcium, sodium, potassium
- ASTHENOSPHERE-- zone of weak rock capable of plastic flow, located in the upper mantle



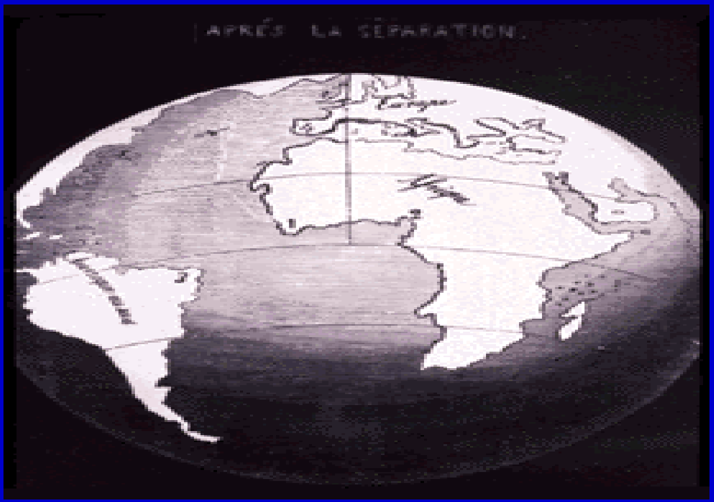
TRENDS WITHIN EARTH'S INTERIOR

- Density of materials increases with depth below the surface.
- Pressure on materials increases with depth below the surface.
- Temperature of materials increases with depth below the surface.

MAJOR PLATES OF THE WORLD

- The crust is composed of about 13 major plates and other smaller plates that move relative to one another.

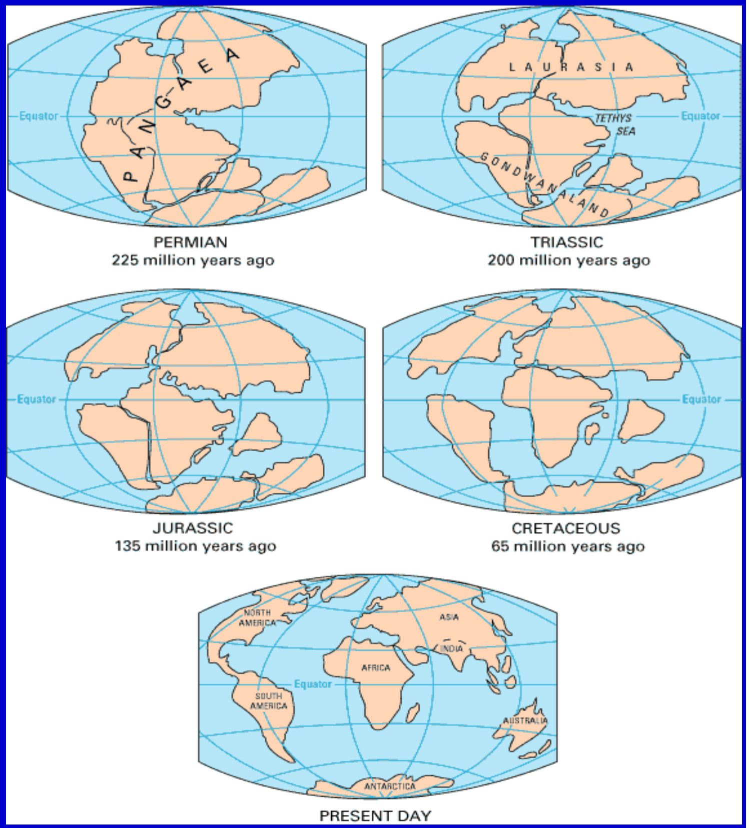
HISTORICAL PERSPECTIVE



- In 1858, geographer Antonio Snider-Pellegrini made these two maps showing his version of how the American and African continents may once have fit together, then later separated. Top: The formerly joined continents before their separation. Bottom: The continents after the separation.

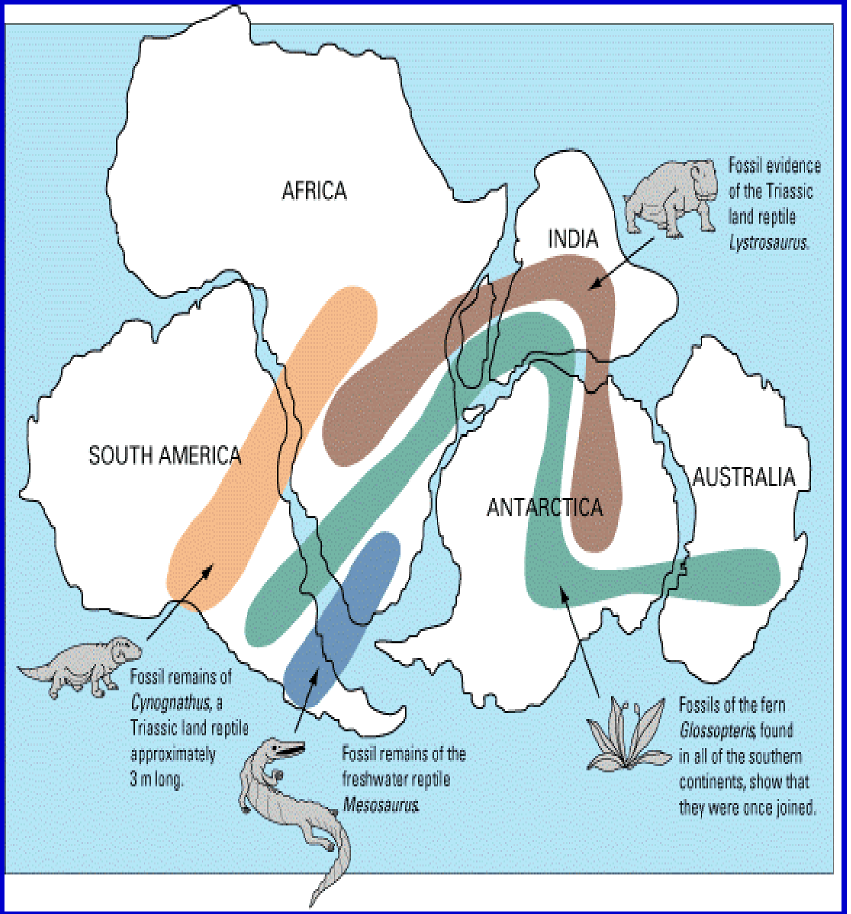
CONTINENTAL DRIFT AND ALFRED WEGENER

- In 1914, Alfred Wegener, a German meteorologist, became intrigued by the apparent fit of South America and Africa as were others before him. He sought out geologic evidence to help support this fit of the continents. He proposed that a supercontinent, (Pangea) existed and broke apart about 200 million years ago to form the continents of Laurasia and Gondwanaland. These landmasses continued to break apart formed the continents that we now recognize. He published a book, “The origin of Continents and Oceans”. The theory of continental drift was detailed in this book.



WEGENER'S EVIDENCE
FOSSILS

- Wegener's theory was based in part, on what appeared to be the remarkable fit of the South American and African continents. He also noted that identical fossils were found on the continents of the southern hemisphere. He reasoned that it was impossible for the animals to swim the vast distances and thought that there distribution was best explained if the continents were joined.



WEGENER'S EVIDENCE
GLACIAL DEPOSITS

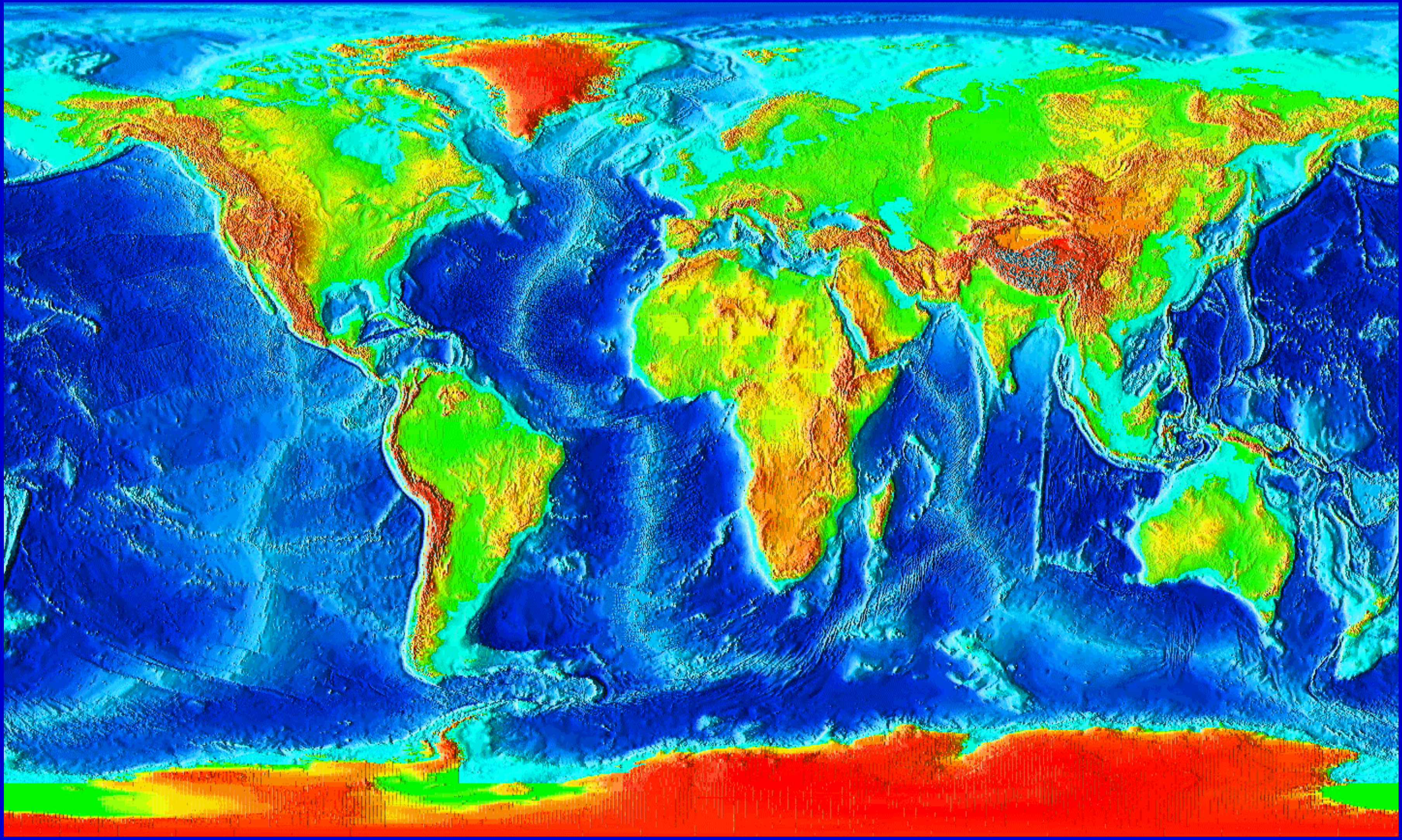
- Geological anomalies, such as glacial deposits occurring in the southern hemisphere and coal deposits found in Antarctica, are best explained if the continents were joined. A weakness of the theory was that Wegener thought the continents plowed through the ocean floor. Needless to say, Wegener's theory was not widely accepted.

The distribution of glacial features can be best explained if the continents were part of Pangaea.

DEVELOPING THE THEORY

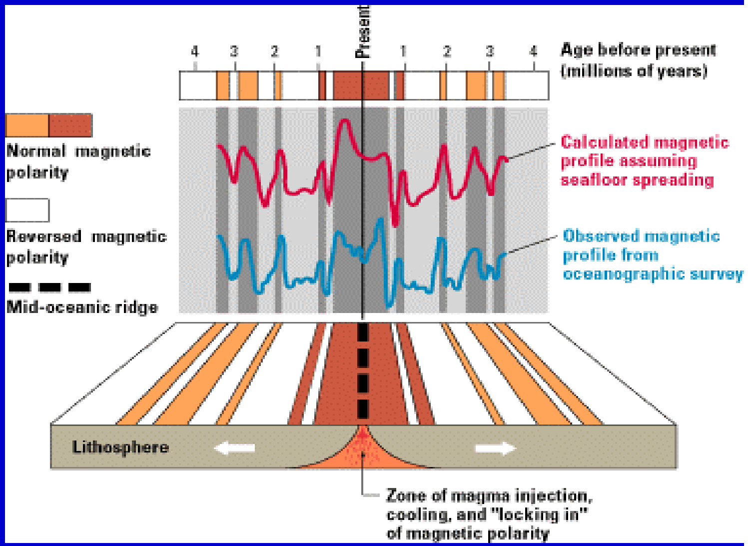
- Continental drift was hotly debated for a time but then dismissed as being preposterous. In the 1950's, however, evidence began to emerge that revived the debate over the theory of continental drift. Four scientific developments spurred the renewal of the continental drift theory: (1) demonstration of the ruggedness and youth of the ocean floor; (2) confirmation of reversals in Earth's magnetic field; (3) the idea of seafloor spreading or the recycling of the oceanic crust; (4) documentation that the majority of the world's earthquakes and volcanoes occur along oceanic trenches and mountain ranges.

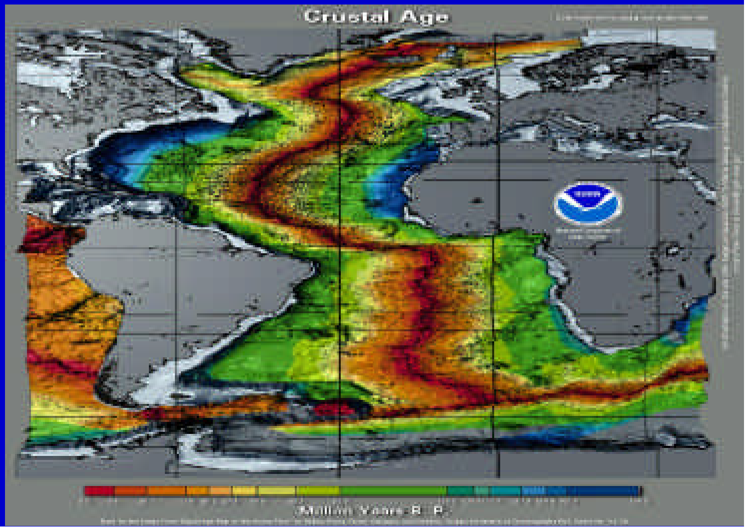
TOPOGRAPHY OF THE SEAFLOOR



MAGNETIC FIELD REVERSALS

- Magnetic surveys of the seafloor revealed reversals in Earth's magnetic field. These stripes were symmetrical around the crests of ocean ridges. Also, the oceanic crust became older away from the ocean ridges. The oldest rocks in the Atlantic Ocean were only 180 million years old. This suggested to scientists that new crust was formed at these ridges and that the oceans moved away from the ridges. The idea of seafloor spreading was born. Plate tectonics evolved from this.

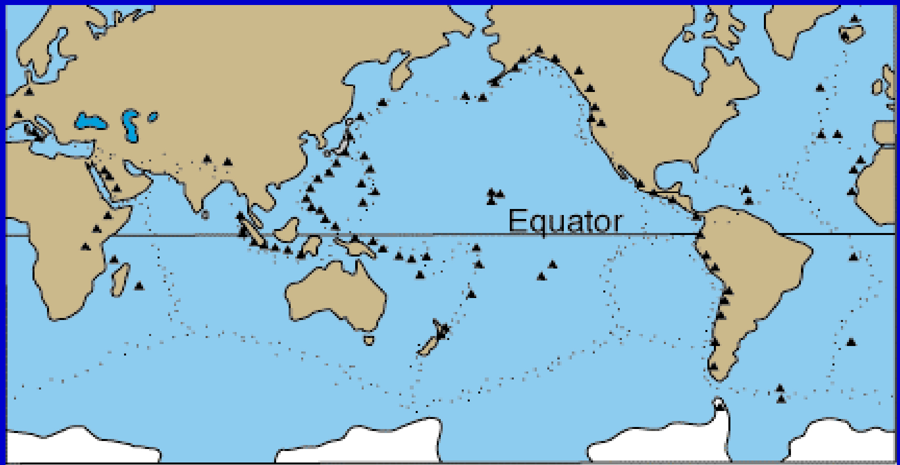




WORLD'S EARTHQUAKES AND VOLCANOES

- These figures show that the majority of the world's earthquakes and volcanoes occur at plate boundaries.

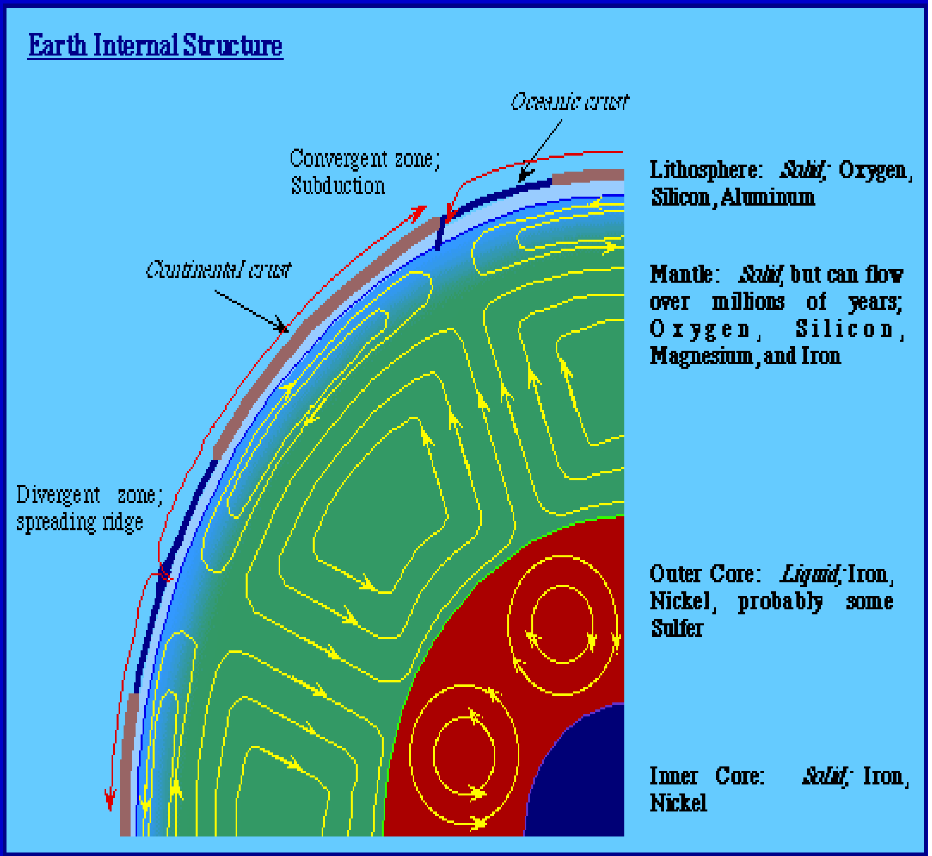
Major tectonic plates of the world.



Global distribution of volcanoes (▲) and earthquakes (· · ·) based on Simkin and others (1989).

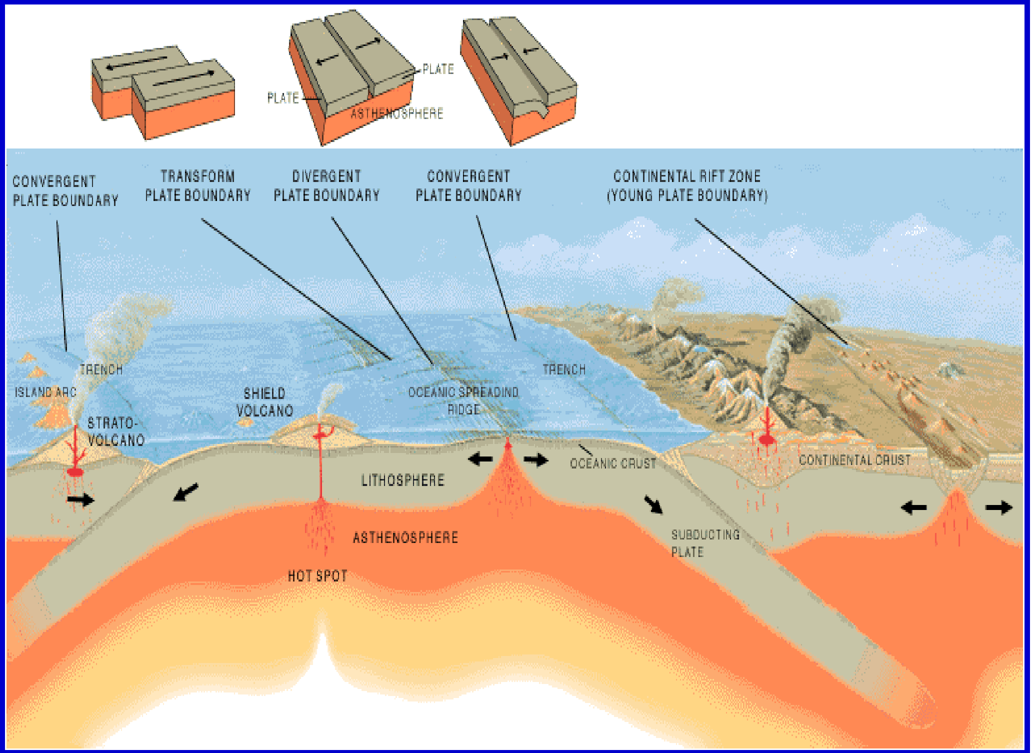
HOW PLATES MOVE

- Movement of plates is driven by flow of heat from Earth's interior. Geologists theorize that convection currents bring hot material upward and, elsewhere, cold rock is brought downward.
  - Conduction--heat flows between objects that are touching
  - Convection--heat is transferred by moving liquid



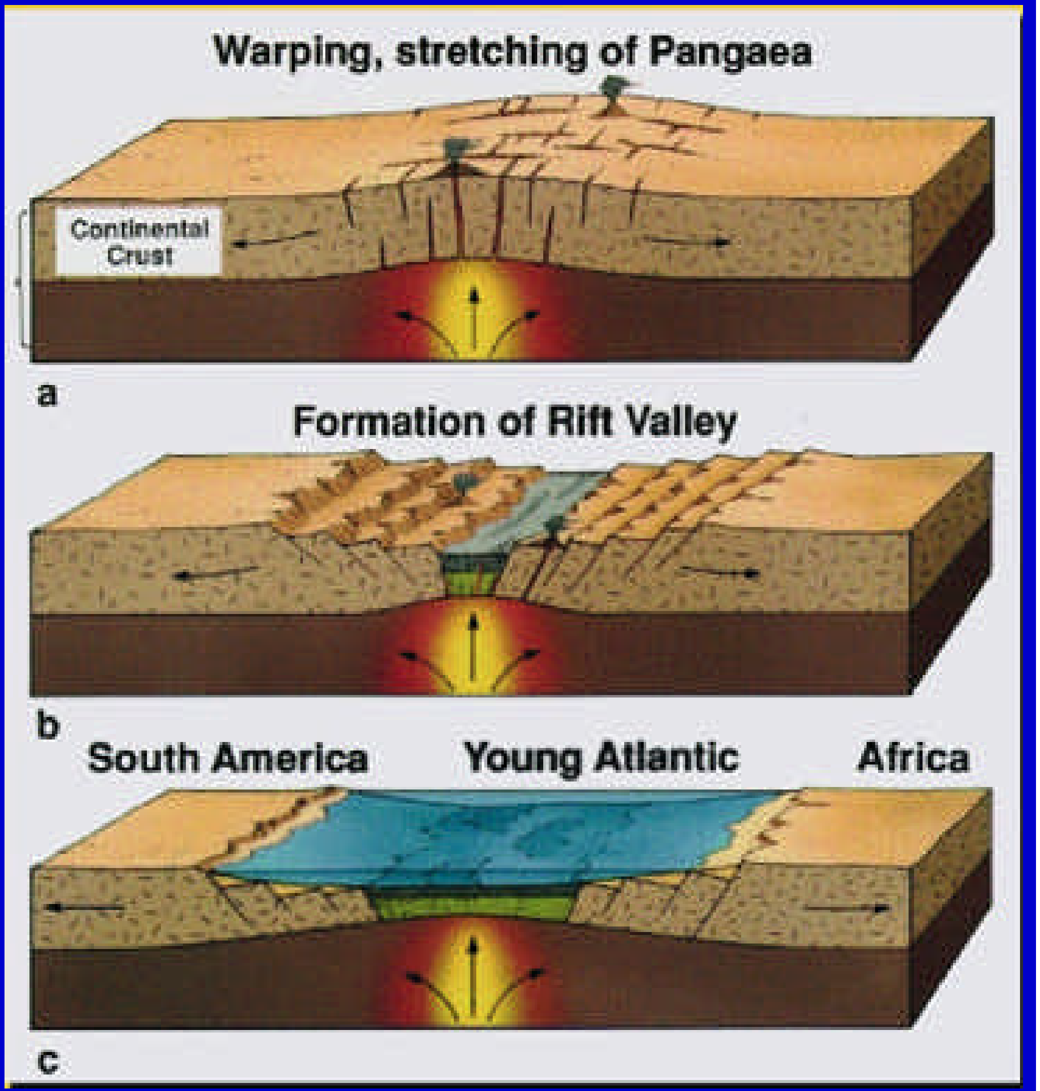
TYPES OF PLATE BOUNDARIES

- DIVERGENT BOUNDARIES (constructive)-- plates move away from each other
- CONVERGENT BOUNDARIES (destructive)-- plates move toward each other
- TRANSFORM BOUNDARIES (conservative) -- plates slide laterally past each other



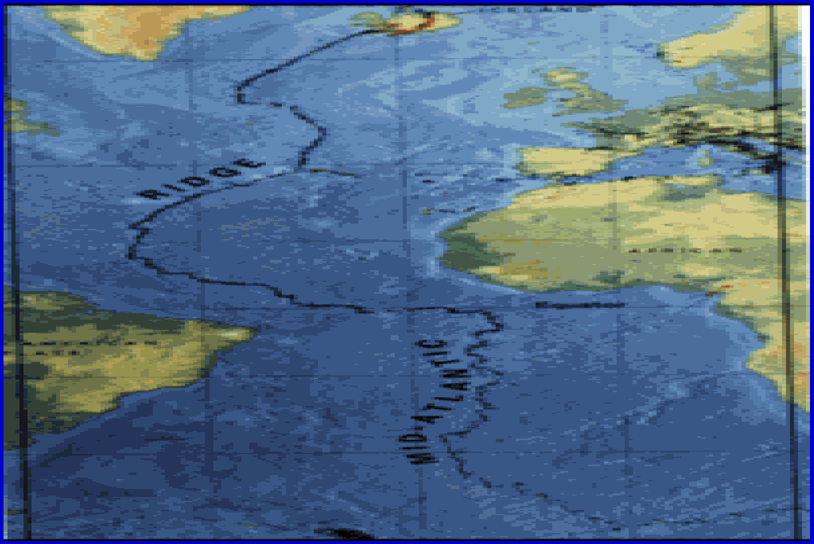
DIVERGENT BOUNDARIES

- Blocks of rock are down-dropped along faults--rift valley e.g.... East African rift
- Magma rises from asthenosphere along rifts-volcanic activity e.g-- East African rift, mid-ocean ridges
- Plates rift apart along elongate system of fractures



EXAMPLES OF DIVERGENT BOUNDARIES

- Mid-Atlantic ridge



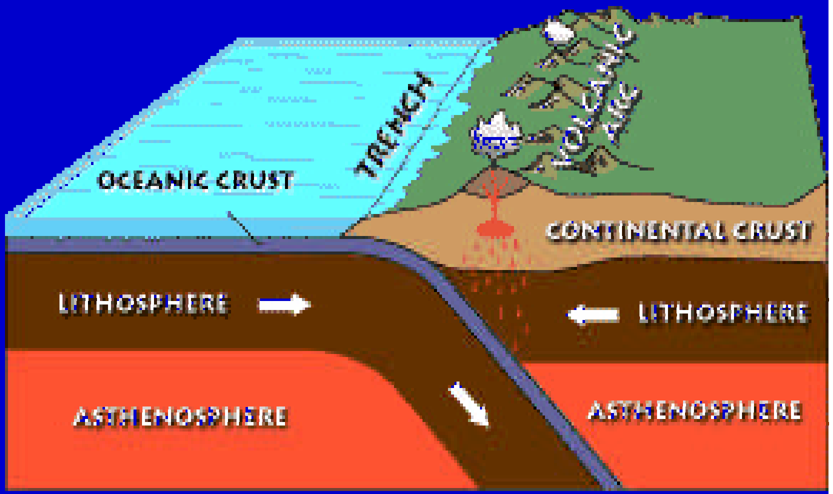
- Mount Oldoinyo: A volcano in the East African rift valley

CONVERGENT BOUNDARIES

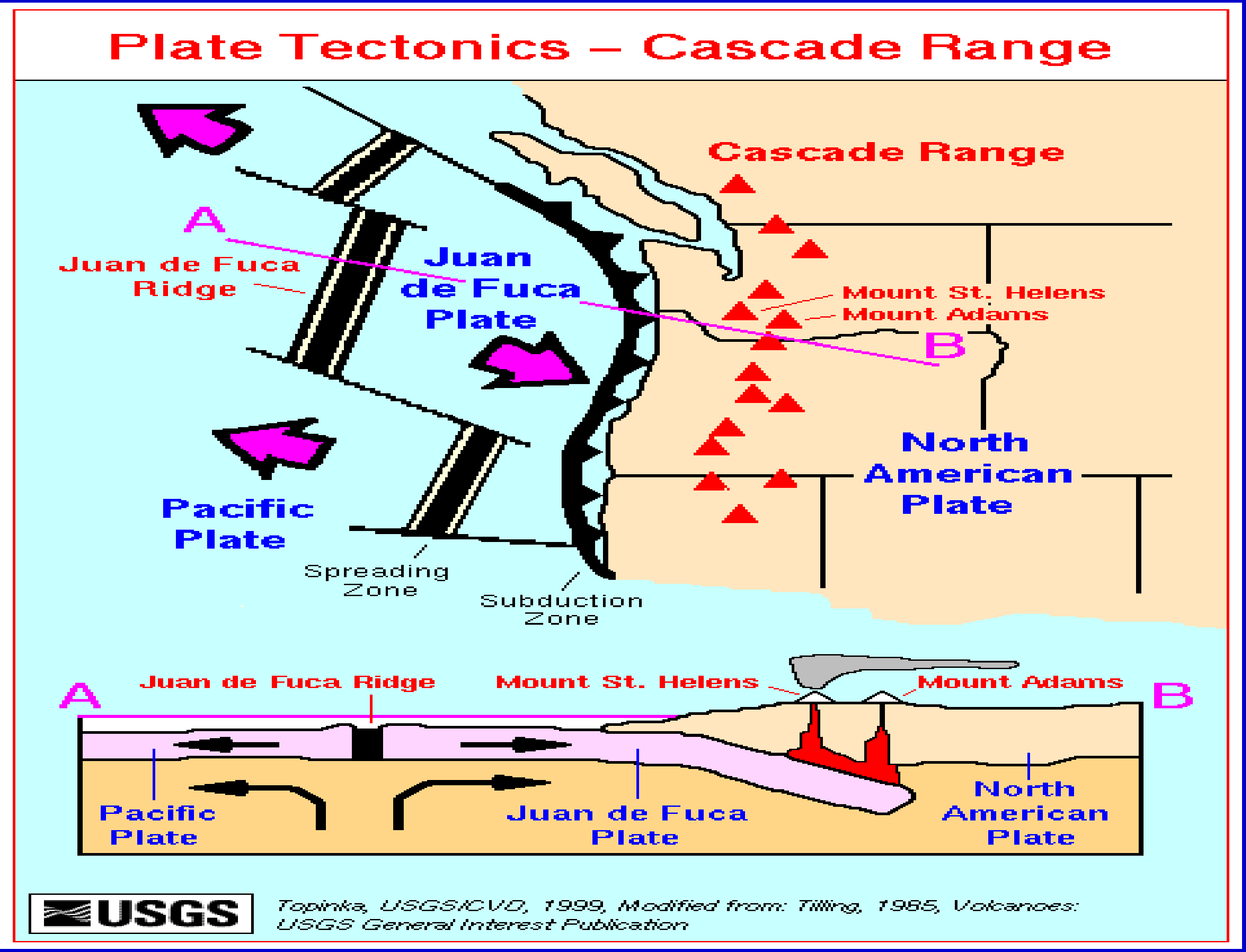
- OCEANIC PLATE VERSUS CONTINENTAL PLATE
- OCEANIC PLATE VERSUS OCEANIC PLATE
- CONTINENTAL PLATE VERSUS CONTINENTAL PLATE

OCEANIC VERSUS CONTINENTAL PLATE COLLISION

- As the dense oceanic plate collides with the less dense continental plate, it begins to sink into the asthenosphere and a subduction zone is formed. Where the two plates join, a trench is formed. As the plate sinks, it begins to melt, forming magma which can form large bodies of intrusive igneous rocks or, if it reaches the surface volcanic mountain ranges such as the Andes and Cascade mountains. Subduction zones can produce large-magnitude earthquakes as the plates slide past each other.



EXAMPLE OF OCEAN-CONTINENT COLLISION

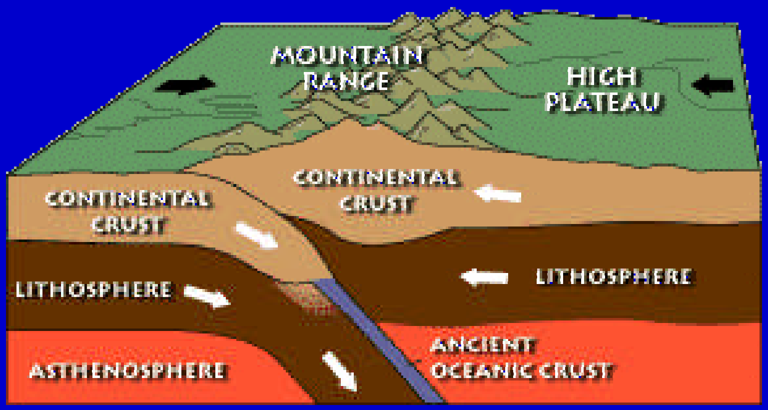


OCEANIC VERSUS OCEANIC PLATE CONVERGENCE

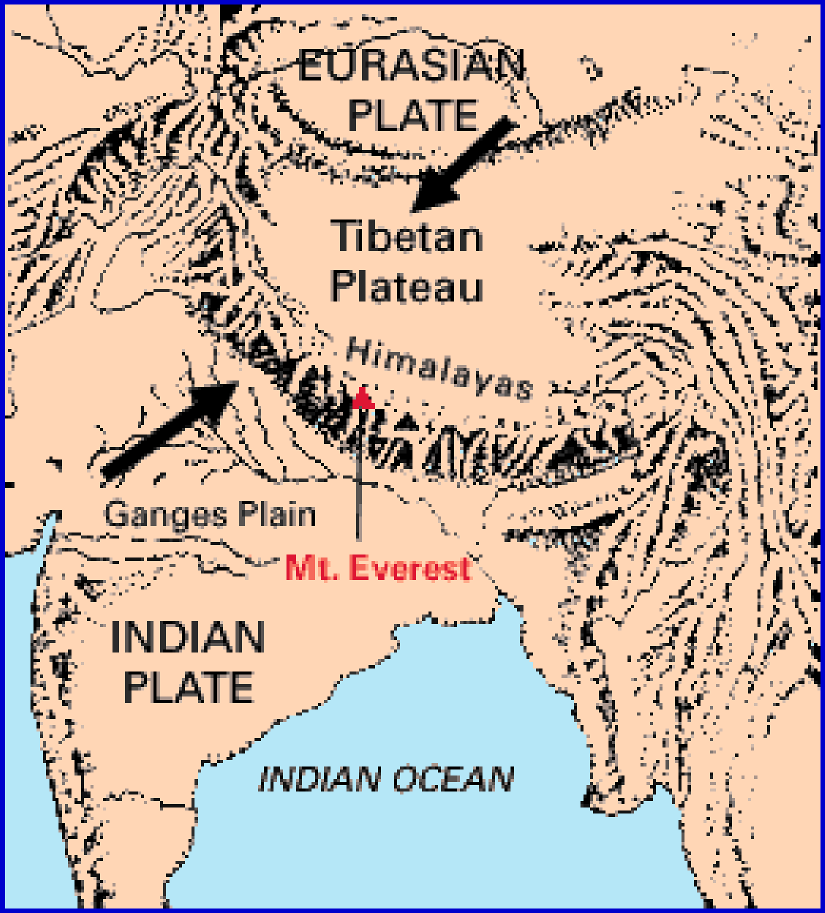
- When oceanic plates collide, the older plate will be subducted because it is slightly denser than the younger plate. A subduction zone is formed with its active trench. A curved volcanic mountain range is formed over the subduction zone . This time the volcanoes build up from the seafloor and are called island arcs. The Aleutian Islands and the Philippine Islands are examples of island arcs. Large-magnitude earthquakes can originate within the subduction zone.

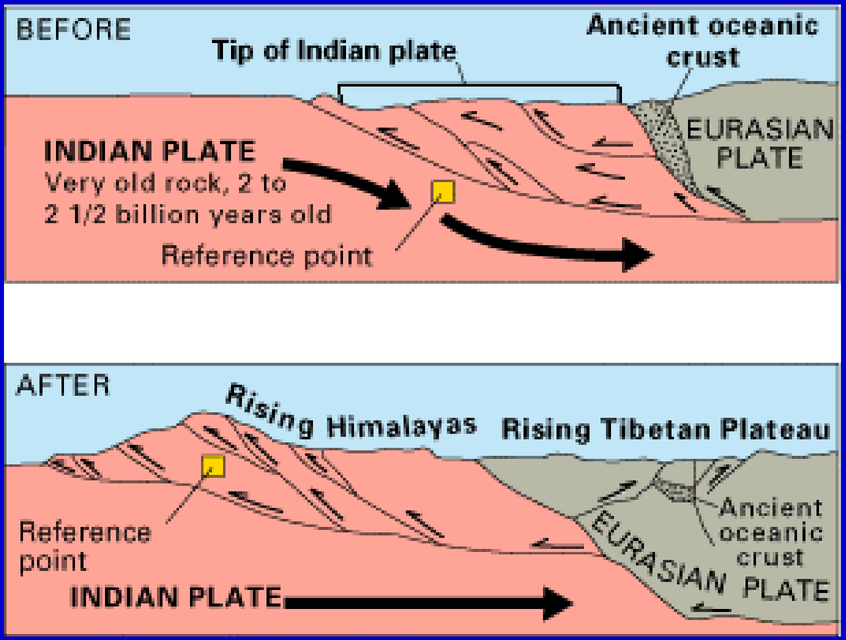
CONTINENTAL VERSUS CONTINENTAL PLATE COLLISION

- When two masses of continental lithosphere collide, neither one can sink because both plates are too buoyant. At these boundaries, solid rock is folded and faulted. Huge slivers of rock are thrust upon one another. The highest mountain ranges in the world are found at these boundaries.   Large-magnitude earthquakes are possible. The Himalayan Mountains where India is colliding with Asia is an example.



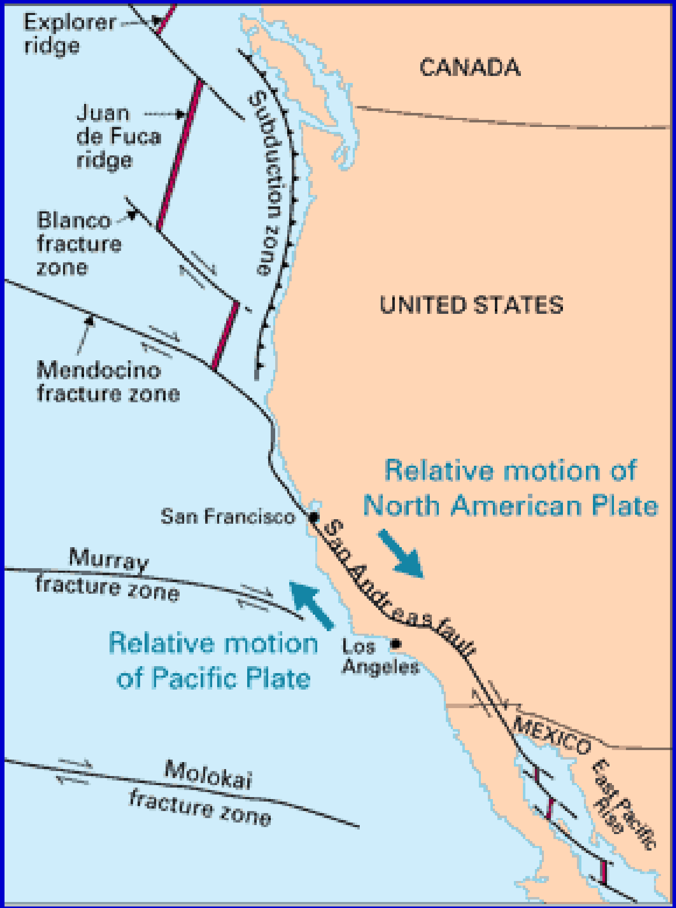
EXAMPLE OF CONTINENT-CONTINENT COLLISION



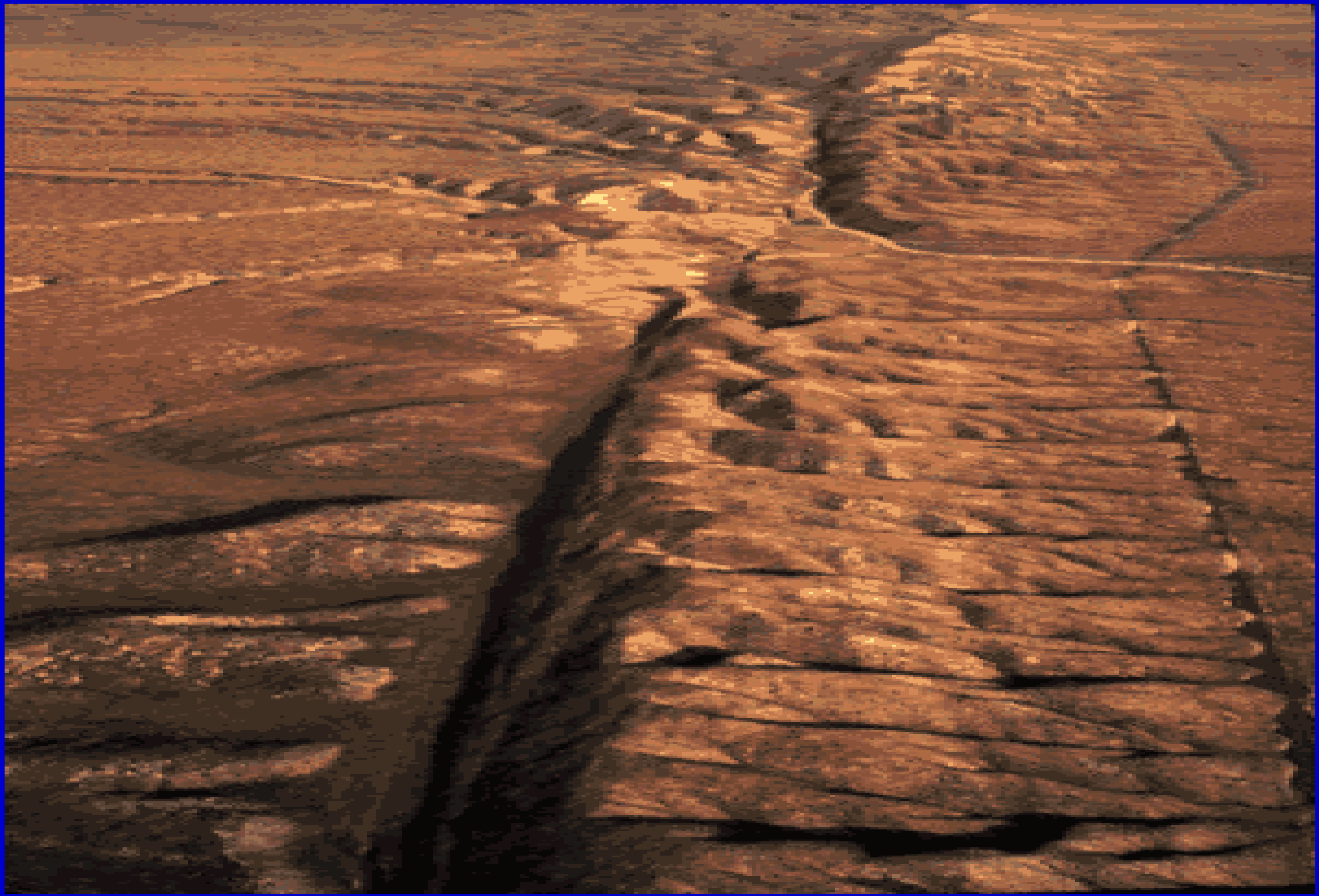


TRANSFORM BOUNDARIES

- At transform boundaries, plates grind and slide laterally by one another. This type of boundary separates the North American plate from the Pacific plate along the San Andreas fault. The motion along this boundary is responsible for many of California's earthquakes.

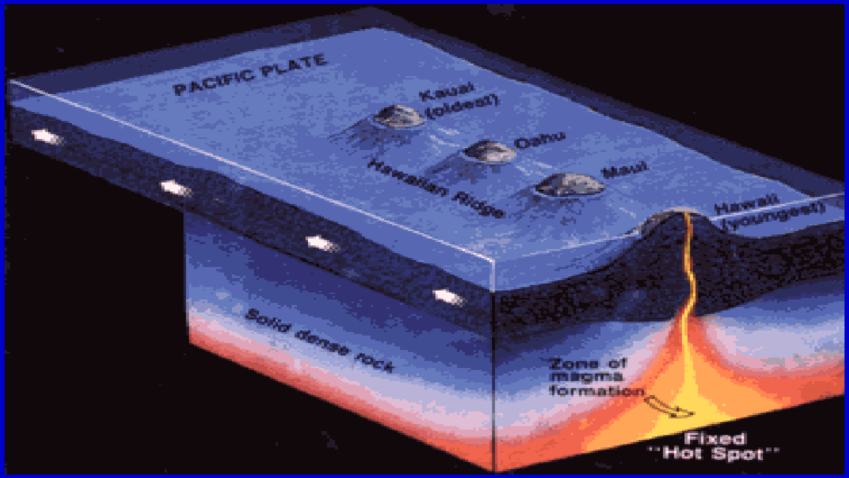


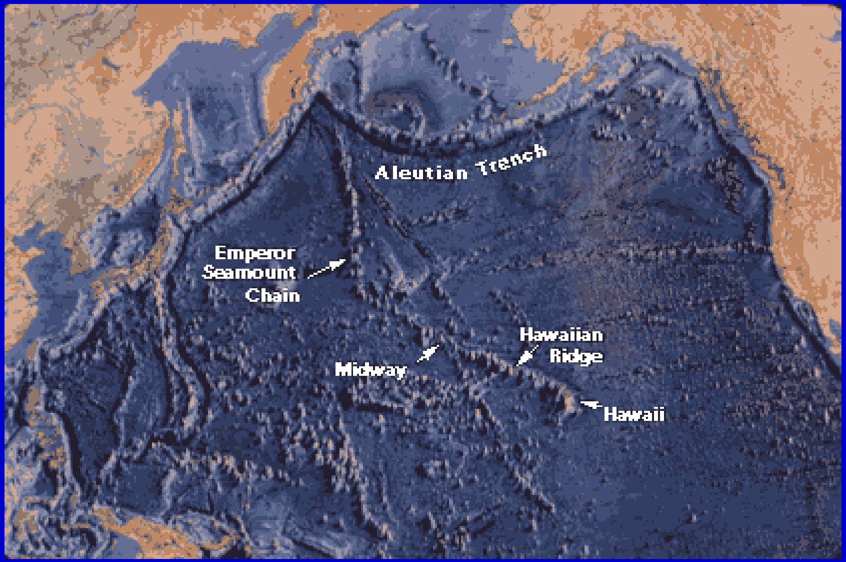
EXAMPLE OF TRANSFORM BOUNDARY



HOTSPOTS

- Hotspots are long-lasting, exceptionally hot regions existing below the plates that provide sources of high heat energy to sustain volcanism; they are not related to plate boundaries. The lighter magma rises through the mantle and crust to erupt on the seafloor, forming seamounts and islands
- Examples: Hawaiian Islands-Emperor seamounts chain, Yellowstone





EARTHQUAKES

- An earthquake is a sudden motion or shaking of the Earth as rocks break and move. This movement causes seismic waves to move along the surface of the Earth and move through the Earth.

TYPES OF SEISMIC WAVES

Body waves: travel through Earths interior

- P-Waves
- S-Waves

Surface waves: travel along Earth’s surface

- Rayleigh Waves
- Love Waves

BODY WAVES

- P-Wave (primary wave) is a compressional wave, that compresses and dilates the rock as it travels forward through the Earth. This is similar to the movement of a spring. Compressional waves can propagate through solids, liquids and gases because all three can sustain changes in density. They are called primary waves because they travel faster and are the first waves to be recorded after the occurrence of an earthquake. The speed at which P waves travel depends upon the properties of the matter through which they propagate. In general, the less dense the matter, the slower the waves.
- S-Wave (secondary wave) is a transverse or shear wave that shakes the rock sideways as it advances at barely more than half the P-wave speed. S-waves only transmit through solids where particles have enough cohesion to be pulled (perpendicular to the direction of travel) by one another.

SURFACE WAVES

Surface waves are the second type of wave. These waves are produced from the arrival of P and S waves at the surface and produce most of the destruction. They are slower than P and S waves and can only travel on the surface of the Earth.

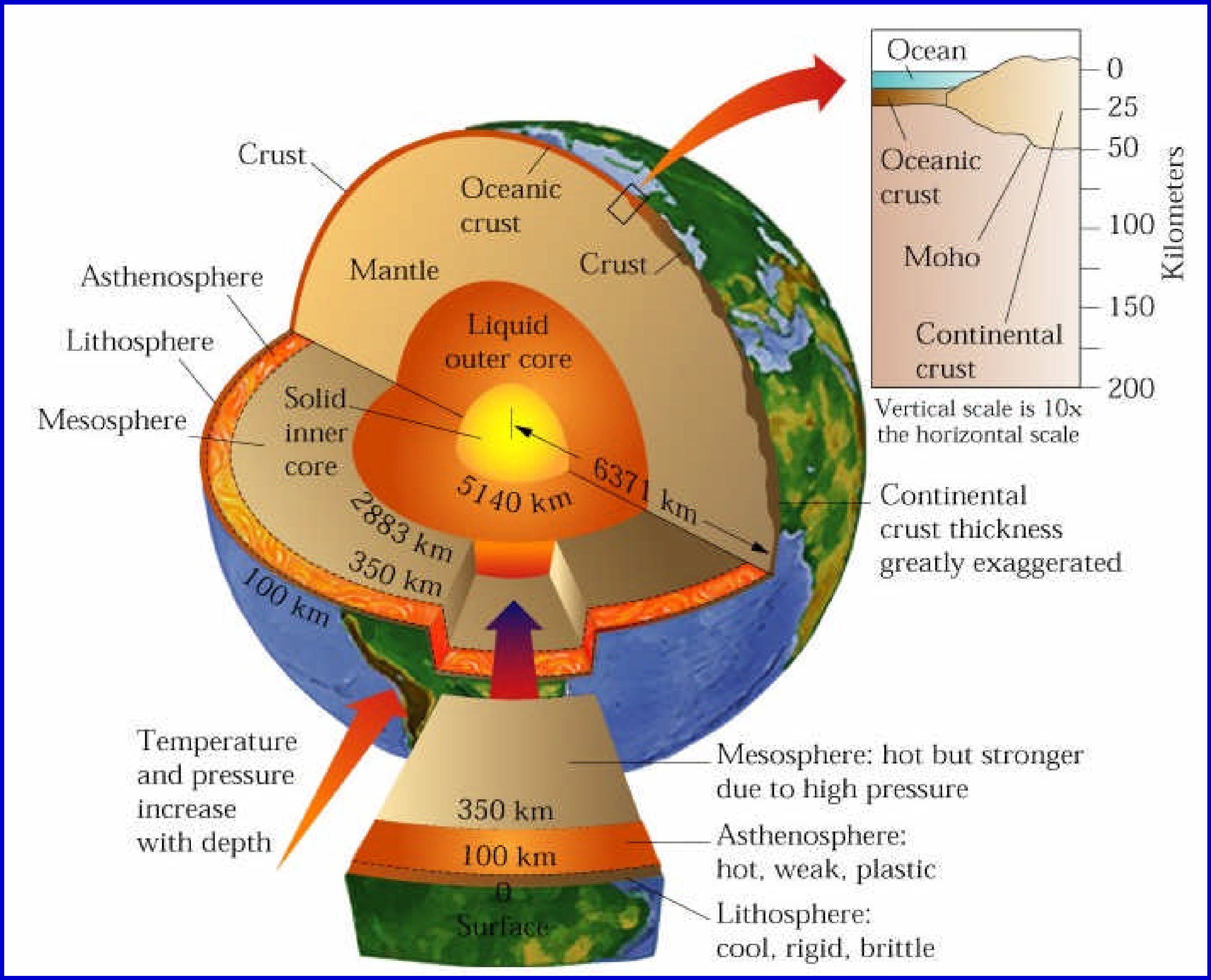
Rayleigh waves produce a rolling motion analogous to waves on the surface of a body of water. An object on the surface will experience both an up-and-down motion transverse to, and a back-and-forth motion parallel to, the propagation direction of the Rayleigh wave. The two components combine to produce a rolling, elliptical motion.

Love waves produce transverse motion -- perpendicular to the direction of wave propagation -- in a horizontal orientation only. This kind of horizontal shearing can be devastating to the foundations of buildings.

THE USE OF SEISMIC WAVES TO DEFINE A LAYERED EARTH

- Seismic waves propagating after an earthquake are refracted by layering and density changes within the earth. Measured at different locations, these waves can give us information about the different densities within the earth. By comparing the velocities of the seismic waves to velocities of known materials, we can make conclusions about the makeup of Earths interior.

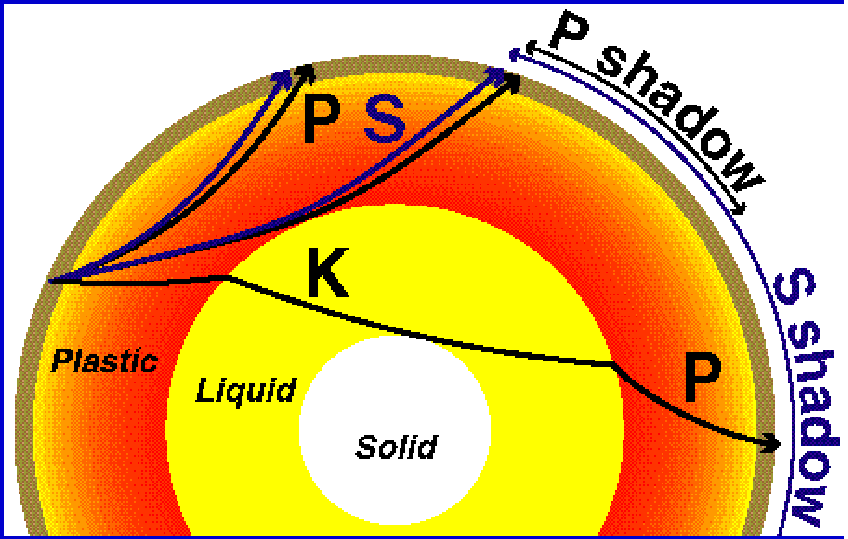
THE EARTH'S INTERIOR



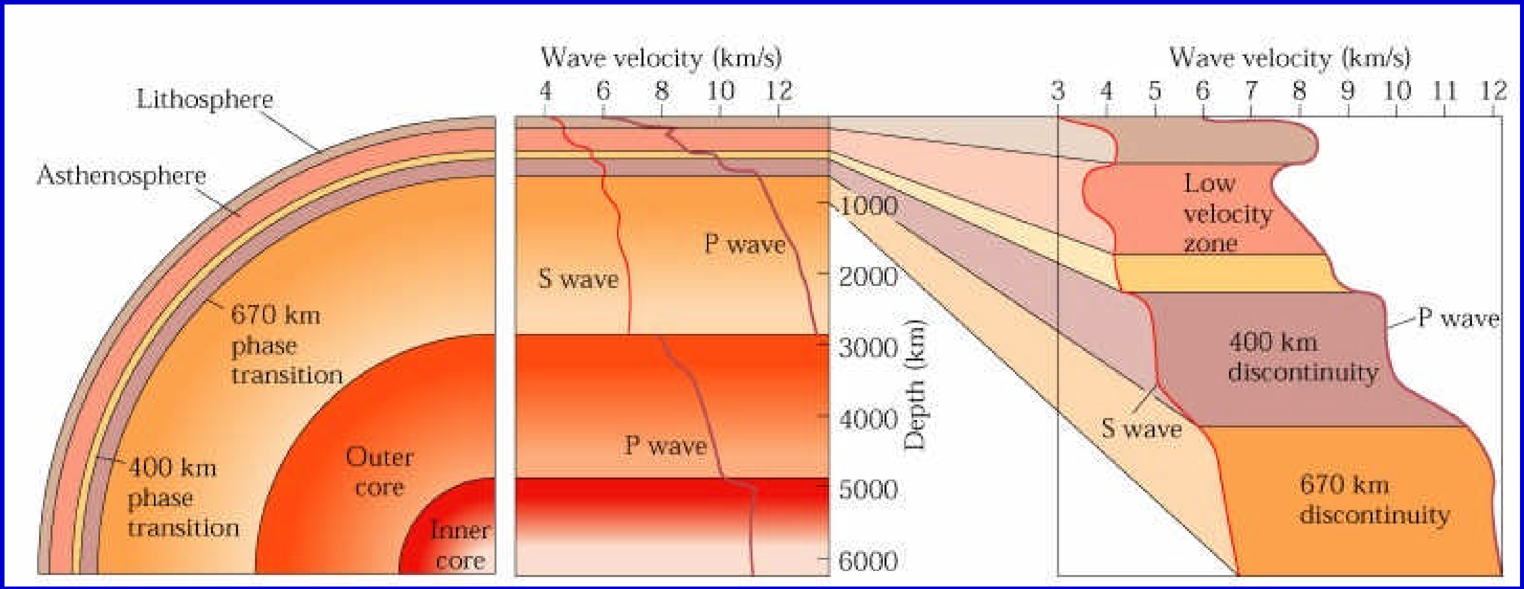
SEISMIC WAVES AND A LAYERED EARTH

- Seismologists noticed that records from an earthquake made around the world changed radically once the event was more than a certain distance away, about 105 degrees in terms of the angle between the earthquake and the seismograph at the center of the earth. After 105 degrees the waves disappeared almost completely, at least until the slow surface waves would arrive from over the horizon. The area beyond 105 degrees distance forms a shadow zone. At larger distances, some P waves would arrive, but still no S waves.

  Conclusion: The Earth has to have a molten, fluid core to explain the lack of S waves in the shadow zone, and the bending of P waves.



VELOCITY CHANGES WITHIN THE EARTH



EARTH HISTORY AND PALEOGEOGRAPHIC RECONSTRUCTIONS OF THE SUPERCONTINENTS

Paleogeographic reconstructions by Christopher R. Scotese

http://www.scotese.com/earth.htm

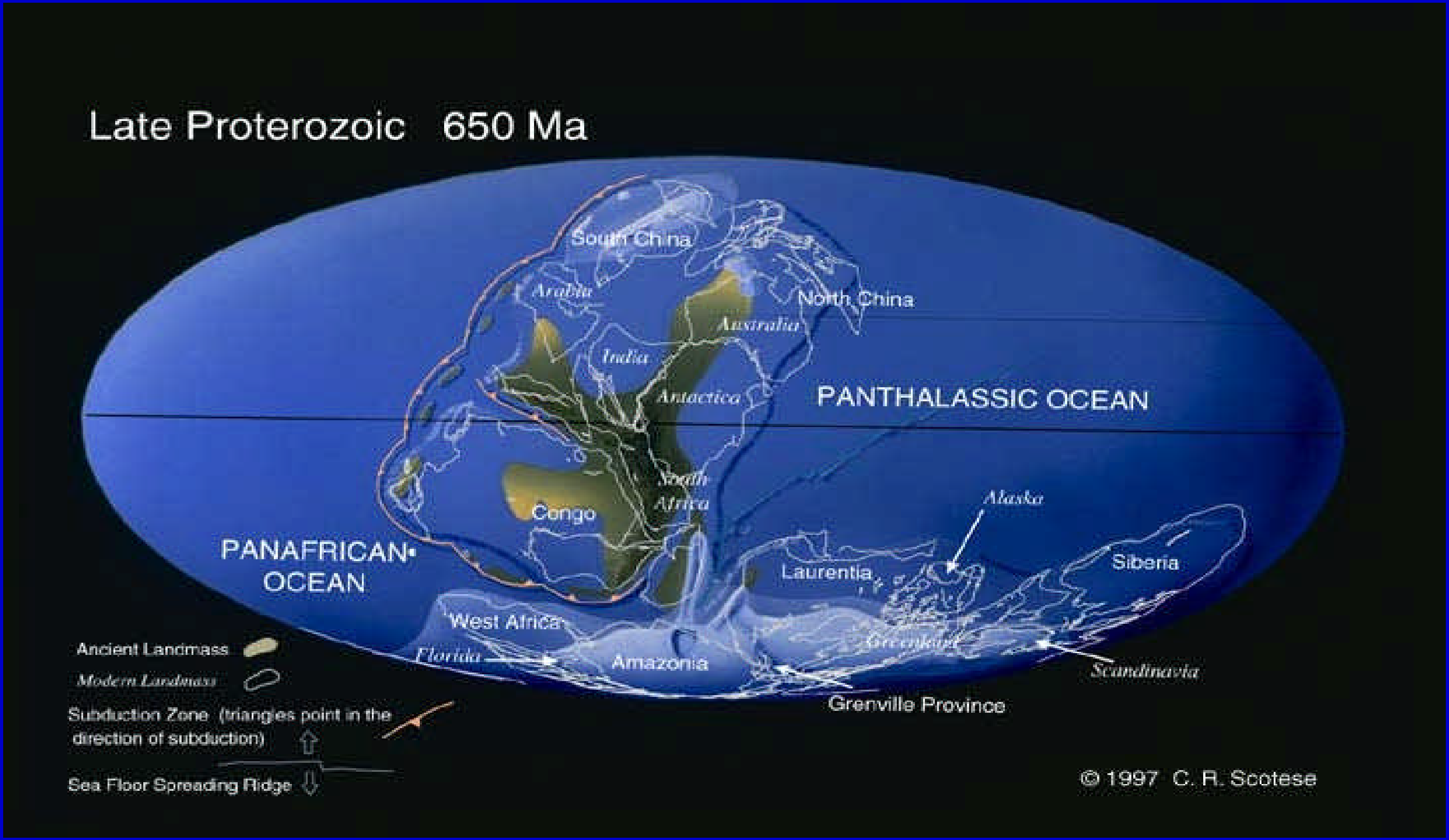
LATE PRECAMBRIAN

The absence of fossils of hard-shelled organisms, and the paucity of reliable paleomagnetic data, make it difficult to produce paleogeographic maps for much of the Precambrian. With available data, 650 million years is about as far back as we can go.

The late Precambrian, however, is an especially interesting time because the continents were colliding to form ancient supercontinents, and because the Earth was locked in a major Ice Age.

About 1,100 million years ago, the supercontinent of Rodinia was assembled. Though its exact size and configuration are not known, it appears that North America formed the core of this supercontinent. At that time, the east coast of North America was adjacent to western South America and the west coast of North America lay next to Australia and Antarctica.

LATE PRECAMBRIAN 650Ma



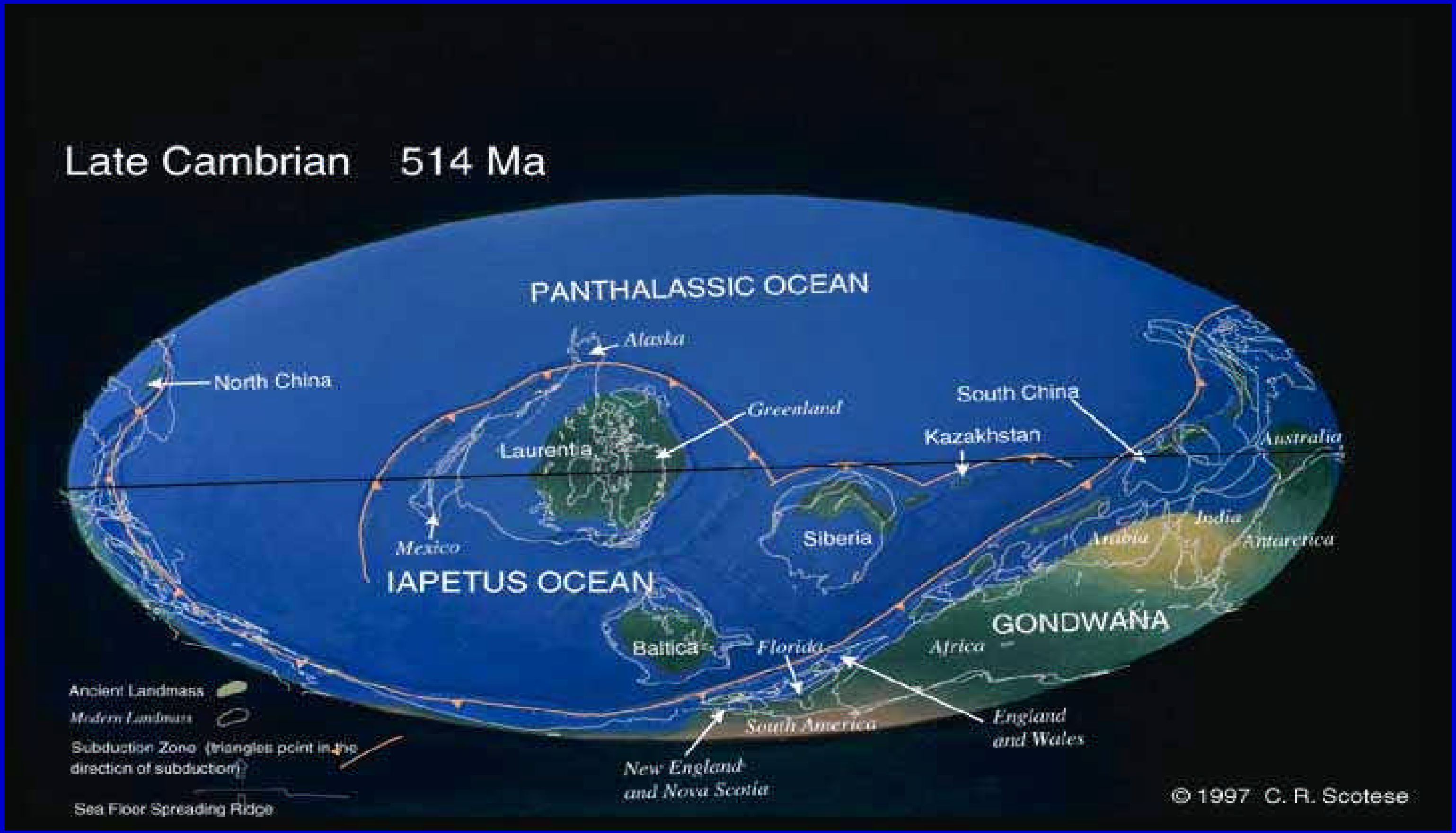
This map illustrates the breakup of the supercontinent, Rodinia, which formed 1,100 million years ago. The Late Precambrian was an "Ice House" world, much like the present-day world.

EARLY PALEOZOIC

Panotia, the supercontinent that formed at the end of the Precambrian Era, approximately 600 million years ago, had already begun to break apart by the beginning of the Paleozoic Era. A new ocean, the Iapetus Ocean, widened between the ancient continents of Laurentia (North America), Baltica (Northern Europe), and Siberia. Gondwana, the supercontinent that was assembled during the Pan-African orogeny, was the largest continent at this time, stretching from the Equator to the South Pole. During the Ordovician Period, warm water deposits, such as limestone and salt, were found in the equatorial regions of Gondwana (Australia, India, China, and Antarctica), while glacial deposits and ice-rafted debris occurred in the south polar areas of Gondwana (Africa and South America).

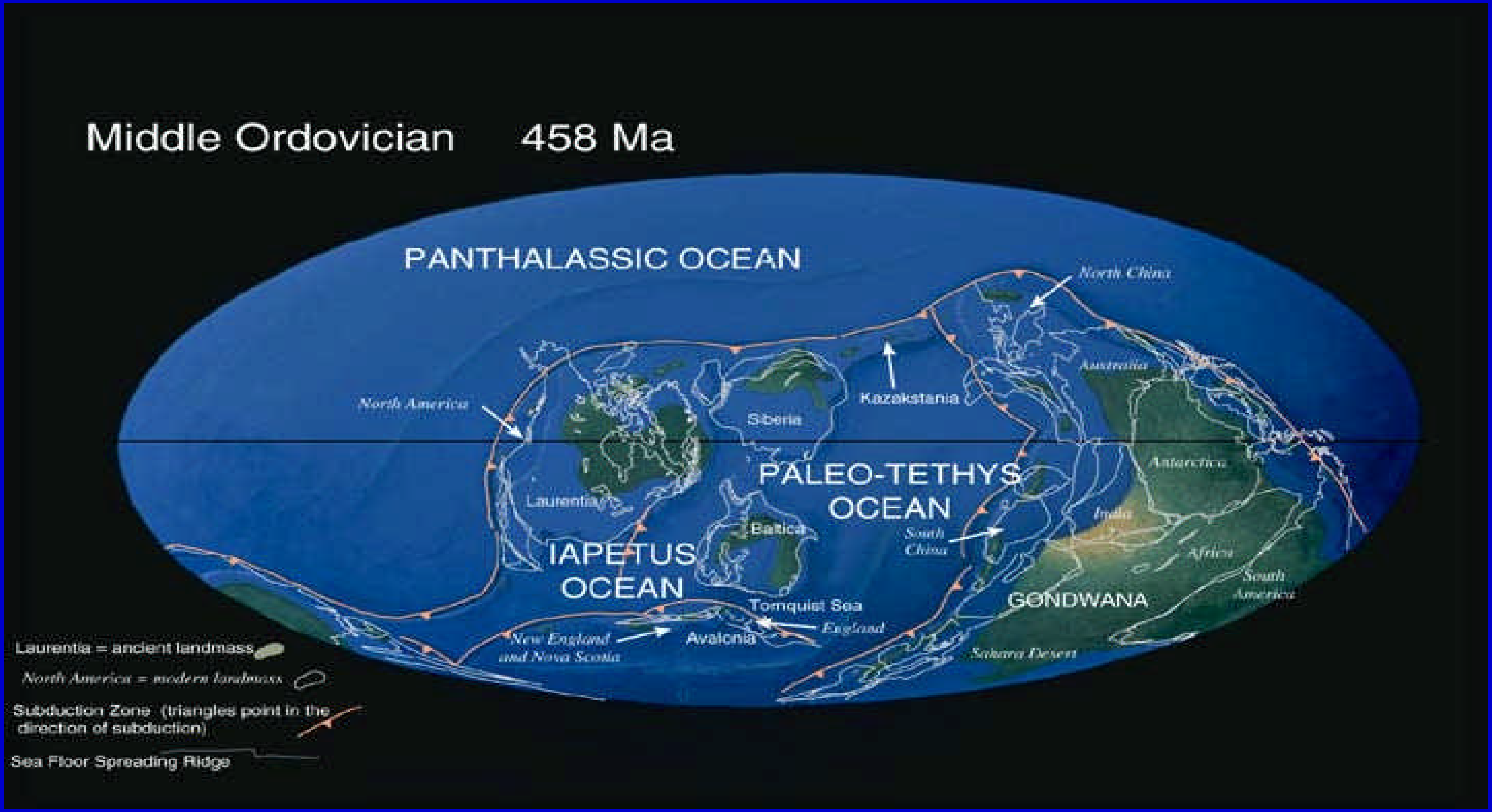
By middle Paleozoic time, approximately 400 million years ago, the Iapetus Ocean had closed, bringing Laurentia and Baltica crashing together. This continental collision, preceded in many places by the obduction of marginal island arcs, resulted in the formation of the Caledonide mountains in Scandinavia, northern Great Britain and Greenland, and the northern Appalachian mountains along the eastern seaboard of North America. It is also likely that by middle Paleozoic times, North China and South China had rifted away from the Indo-Australian margin of Gondwana and were headed northwards across the Paleo-Tethys Ocean. Throughout the Early and Middle Paleozoic, the expansive Panthalassic Ocean covered much of the northern hemisphere. Surrounding this ocean was a subduction zone, much like the modern"ring-of-fire" that surrounds the Pacific Ocean.

LATE CAMBRIAN 514Ma



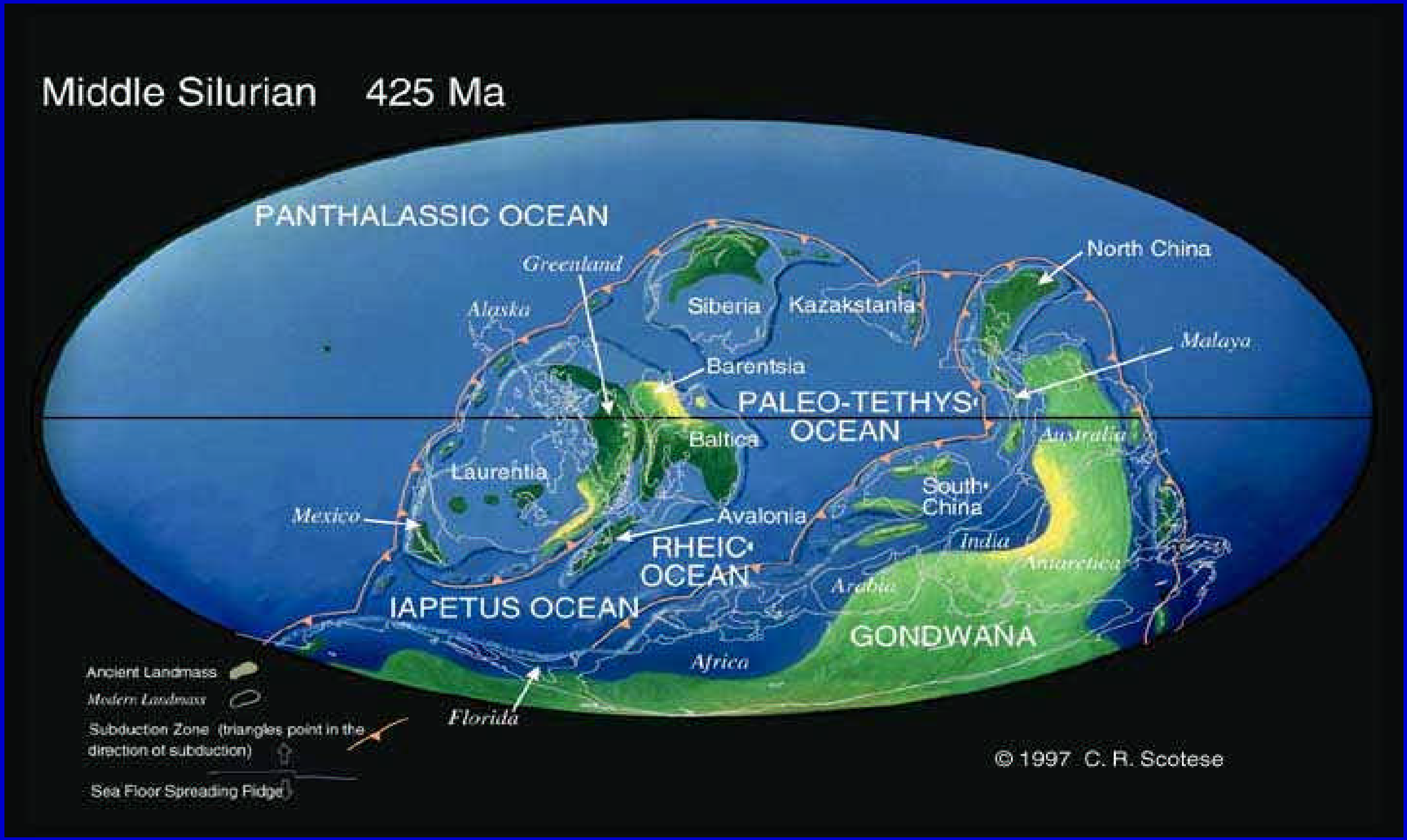
Animals with hard shells appeared in great numbers for the first time during the Cambrian. The continents were flooded by shallow seas. The supercontinent of Gondwana had just formed and was located near the South Pole.

MIDDLE ORDOVICIAN 458Ma



During the Ordovician Period, warm water deposits, such as limestone and salt, were found in the equatorial regions of Gondwana (Australia, India, China, and Antarctica), while glacial deposits and ice-rafted debris occurred in the south polar areas of Gondwana (Africa and South America).

MIDDLE SILURIAN 425Ma

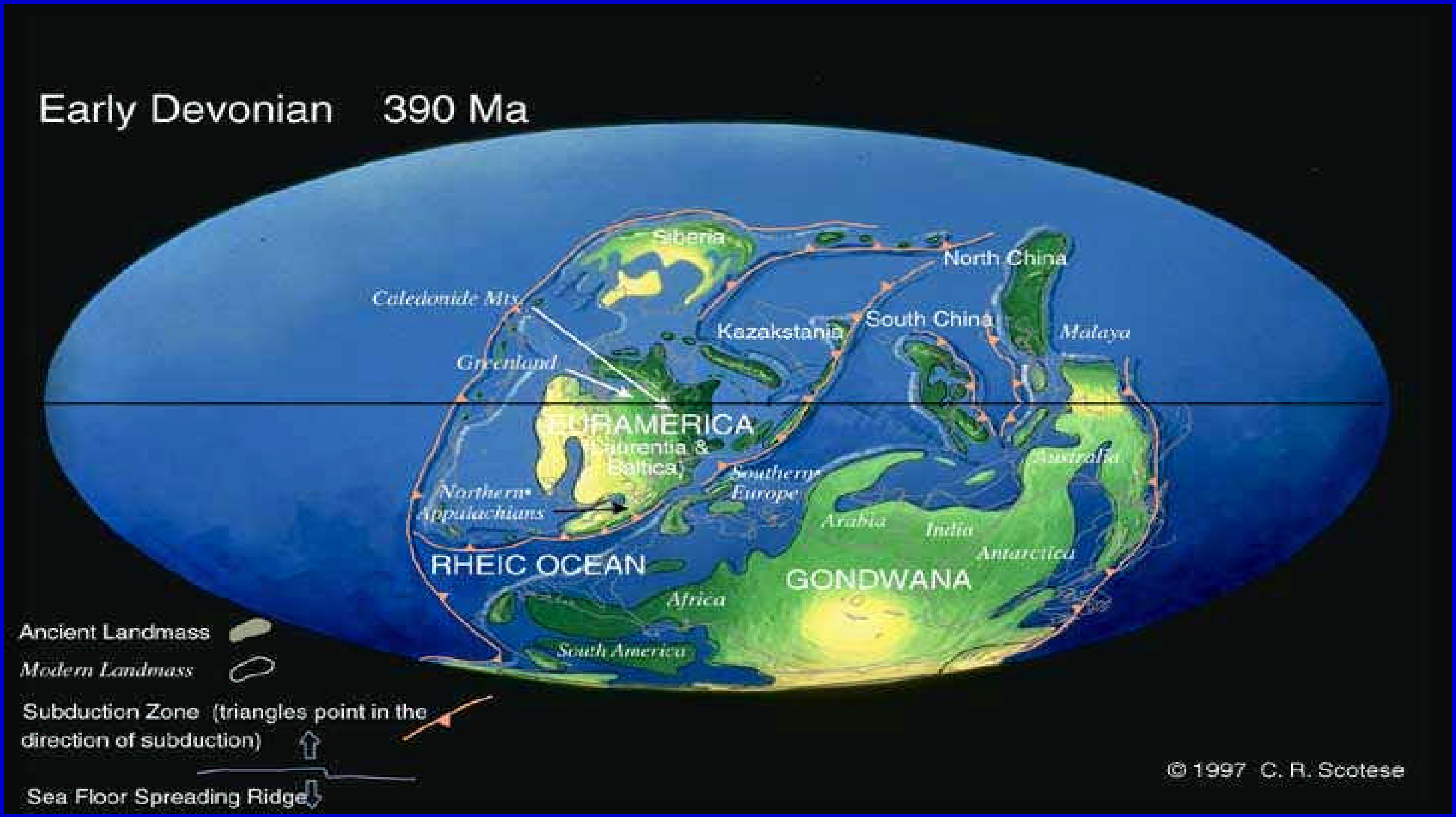


Laurentia collided with Baltica, closing the northern branch of the Iapetus Ocean and forming, the "Old Red Sandstone" continent. Coral reefs expanded and land plants evolved in the rainy regions near the Equator.

THE FORMATION OF PANGEA

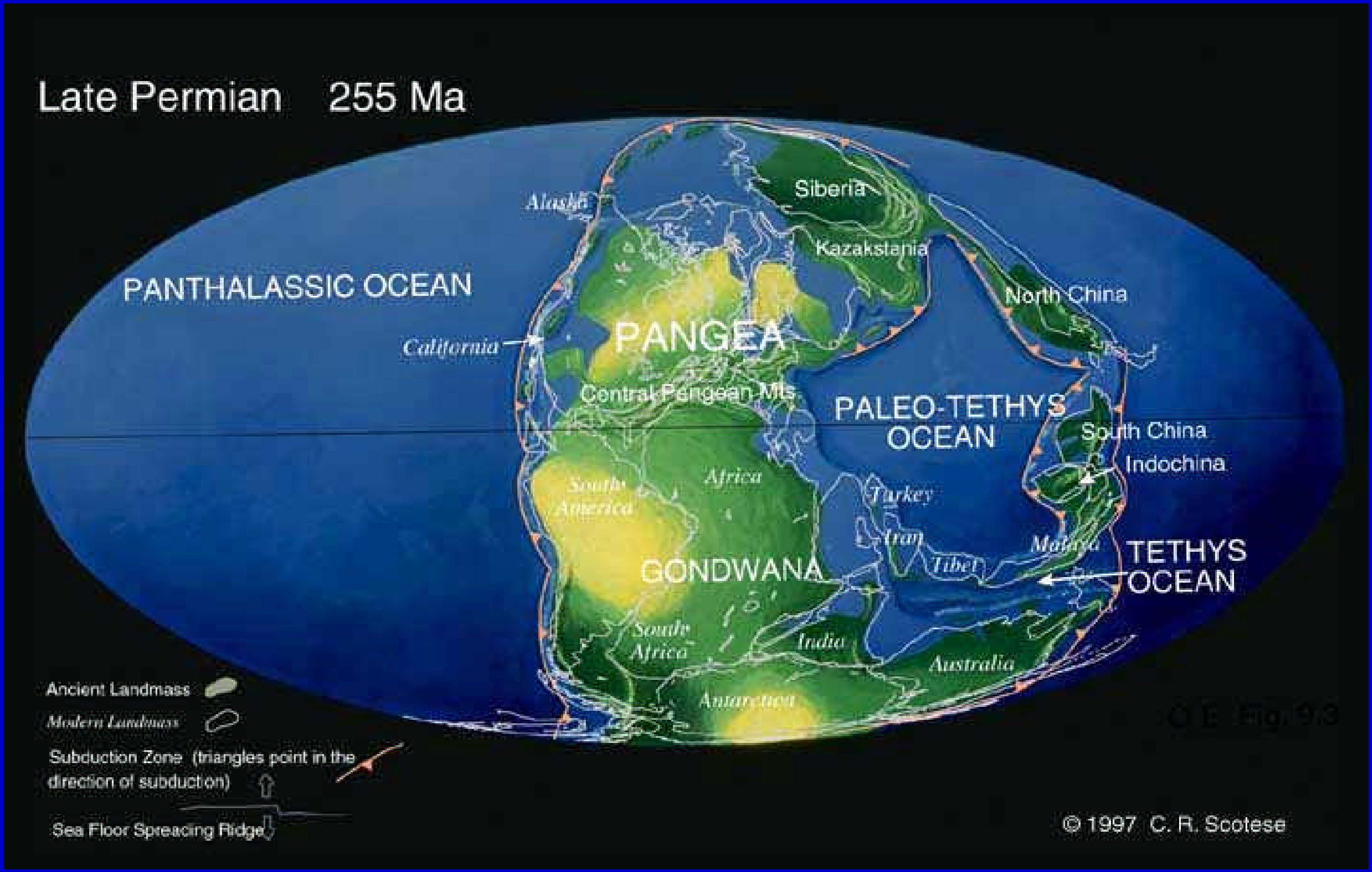
Pangea was assembled piece-wise. The continental collisions that led to the formation of the supercontinent began in the Devonian and continued through the late Triassic.

EARLY DEVONIAN 390Ma



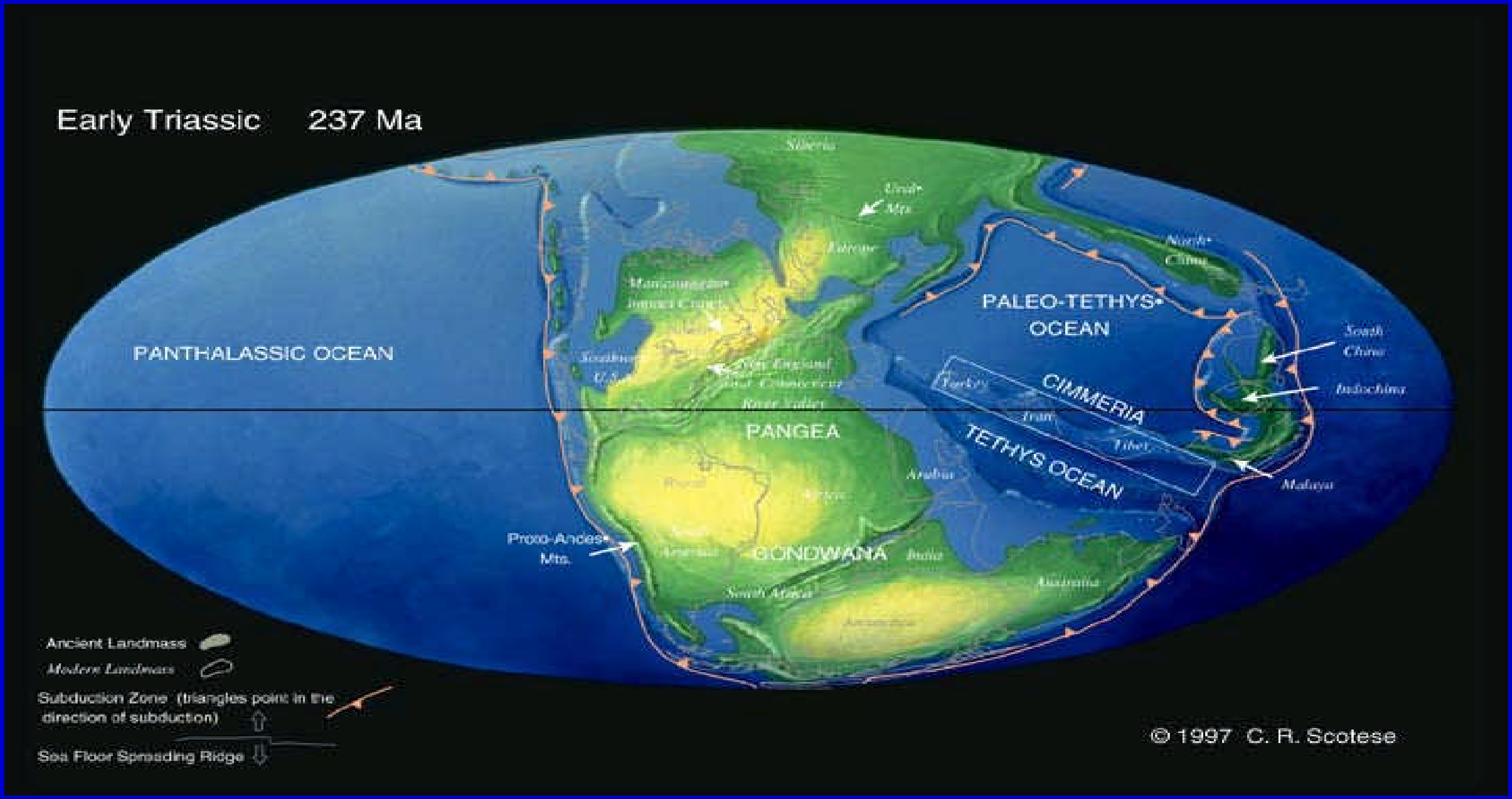
By the Devonian, the early Paleozoic oceans were closing, forming a "pre-Pangea." Freshwater fish were able to migrate from the southern hemisphere continents to North America and Europe. Forests grew for the first time in the equatorial regions of arctic Canada.

LATE PERMIAN 255Ma



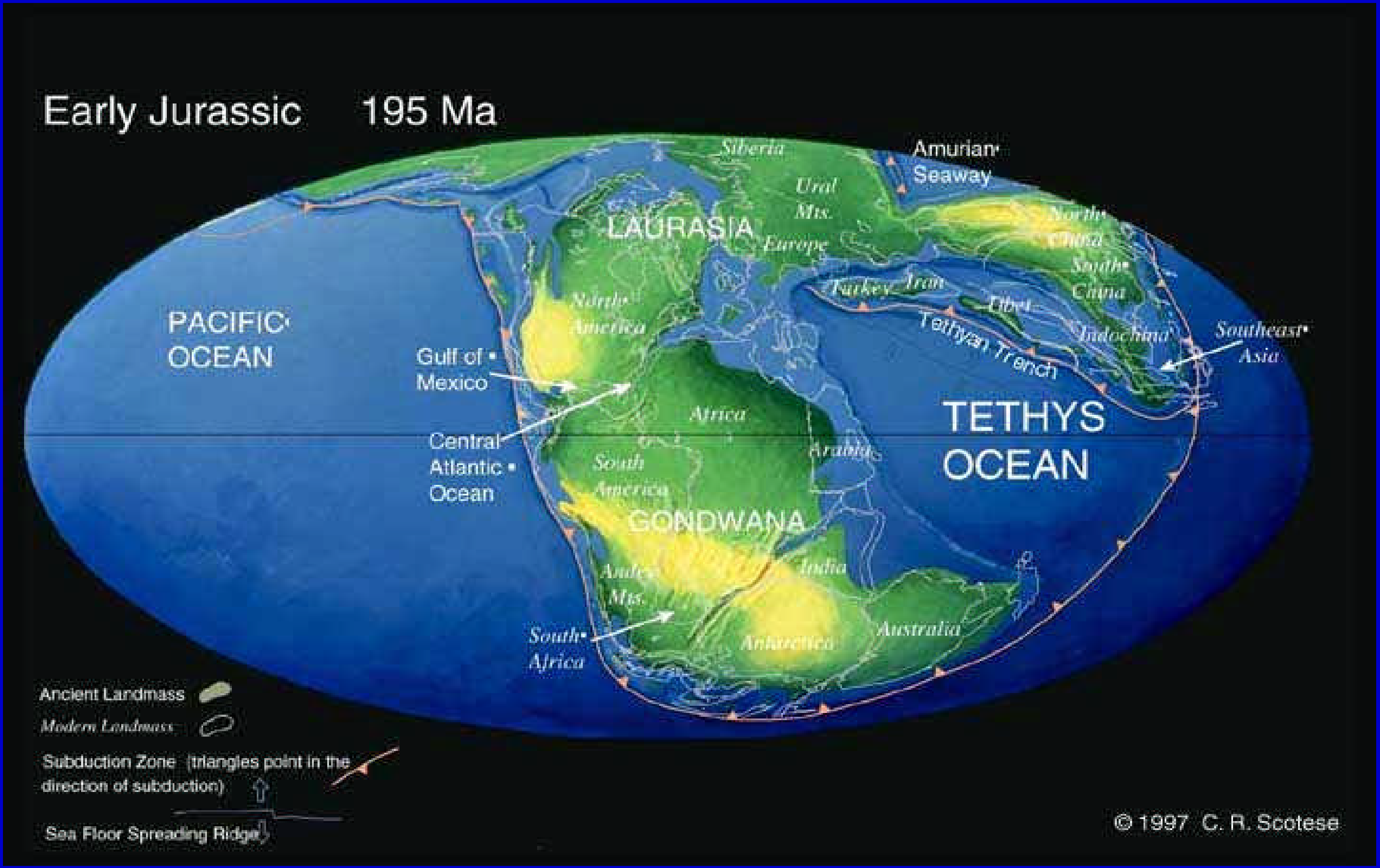
Vast deserts covered western Pangea. Reptiles spread over Pangea and 90 percent of all life perished at the end of the Permian.

EARLY TRIASSIC 232Ma



The supercontinent of Pangea, mostly assembled by the Triassic, allowed land animals to migrate from the South Pole to the North Pole. Life began to rediversify after the great Permian-Triassic extinction and warm-water faunas spread across Tethys.

EARLY JURASSIC 195Ma

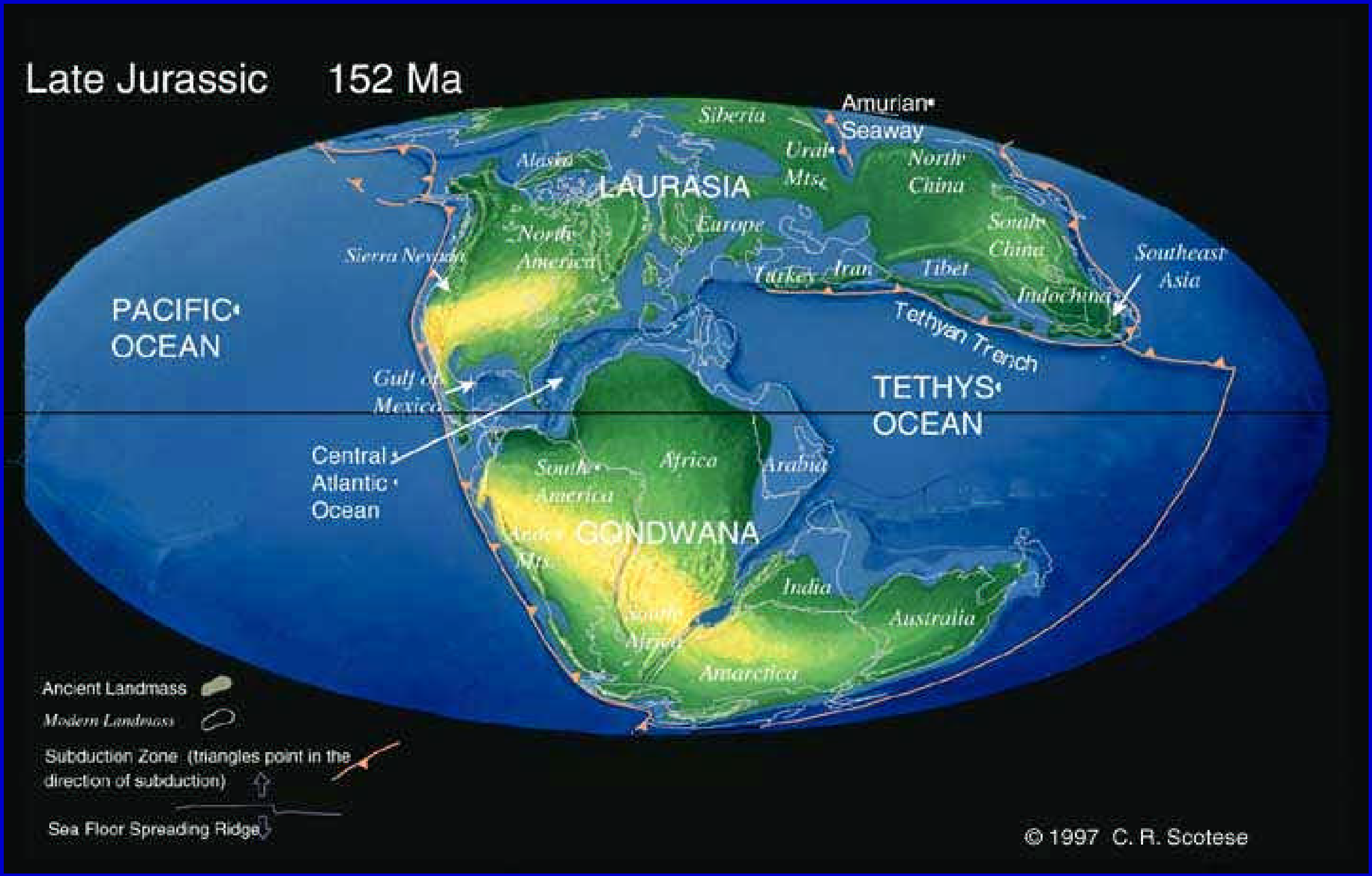


Early Jurassic, the dinosaurs spread across Pangea.

THE BREAKUP OF PANGEA

The supercontinent of Pangea did not rift apart all at once, but rather was subdivided into smaller continental blocks in three main episodes. The first episode of rifting began in the middle Jurassic, about 180 million years ago. After an episode of igneous activity along the east coast of North America and the northwest coast of present-day Africa, the Central Atlantic Ocean opened as North America moved to the northwest (See Late Jurassic). This movement also created the Gulf of Mexico as North America moved away from South America. At the same time, on the other side of present-day Africa, extensive volcanic eruptions along the adjacent margins of east Africa, Antarctica, and Madagascar heralded the formation of the western Indian Ocean. During the Mesozoic, North America and Eurasia were one landmass, sometimes called Laurasia. As the Central Atlantic Ocean opened, Laurasia rotated clockwise, sending North America northward and Eurasia southward. Coals, which were abundant in eastern Asia during the early Jurassic, were replaced by deserts and salt deposits during the Late Jurassic as Asia moved from the wet temperate belt to the dry subtropics. This clockwise, see-saw motion of Laurasia also led to the closure of the wide V-shaped ocean, Tethys, that separated Laurasia from the fragmenting southern supercontinent, Gondwana.

LATE JURASSIC 152Ma



Pangea begins to rift apart.

THE CONTINUED BREAKUP OF PANGEA

India, together with Madagascar, rifted away from Antarctica and the western margin of Australia, opening the Eastern Indian Ocean. The South Atlantic did not open all at once, but The second phase in the breakup of Pangea began in the early Cretaceous, about 140 million years ago. Gondwana continued to fragment as South America separated from Africa, opening the Atlantic Ocean from south to north. That is why the South Atlantic is wider to the south.

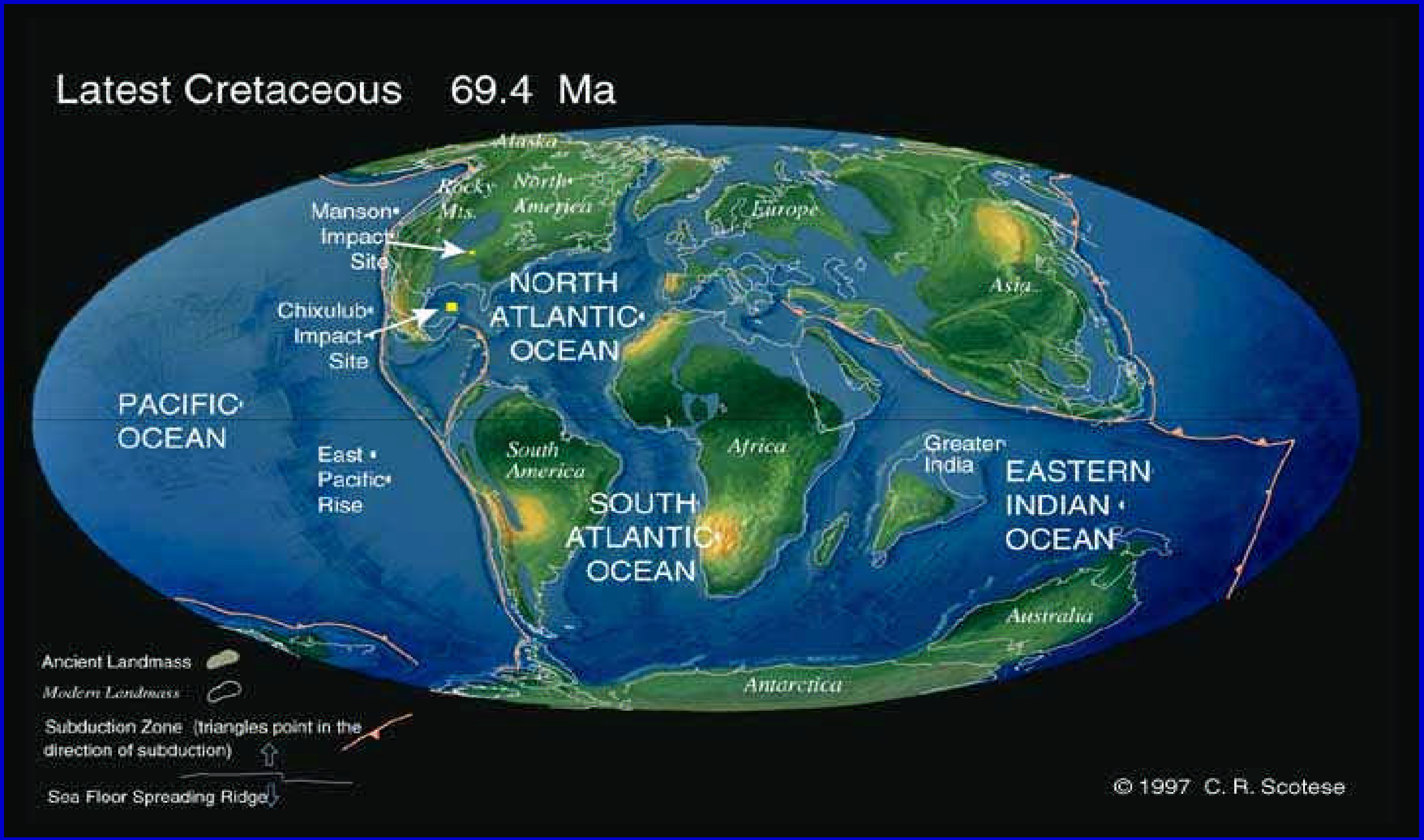
Other important plate tectonic events occurred during the Cretaceous Period. These include the initiation of rifting between North America and Europe, the counter-clockwise rotation of Iberia from France, the separation of India from Madagascar, the derivation of Cuba and Hispaniola from the Pacific, the uplift of the Rocky mountains, and the arrival of exotic terranes (Wrangellia, Stikinia) along the western margin of North America.

Globally, the climate during the Cretaceous Period, like the Jurassic and Triassic, was much warmer than today. Dinosaurs and palm trees were present north of the Arctic Circle and in Antarctica and southern Australia. Though there may have been some at the poles during the Early Cretaceous, there were no large ice caps at anytime during the Mesozoic Era.

These mild climatic conditions were, in part, due to the fact that shallow seaways covered the continents during the Cretaceous. Warm water from the equatorial regions was also transported northward, warming the polar regions. These seaways also tended to make local climates milder, much like the modern Mediterranean Sea, which has an ameliorating effect on the climate of Europe.

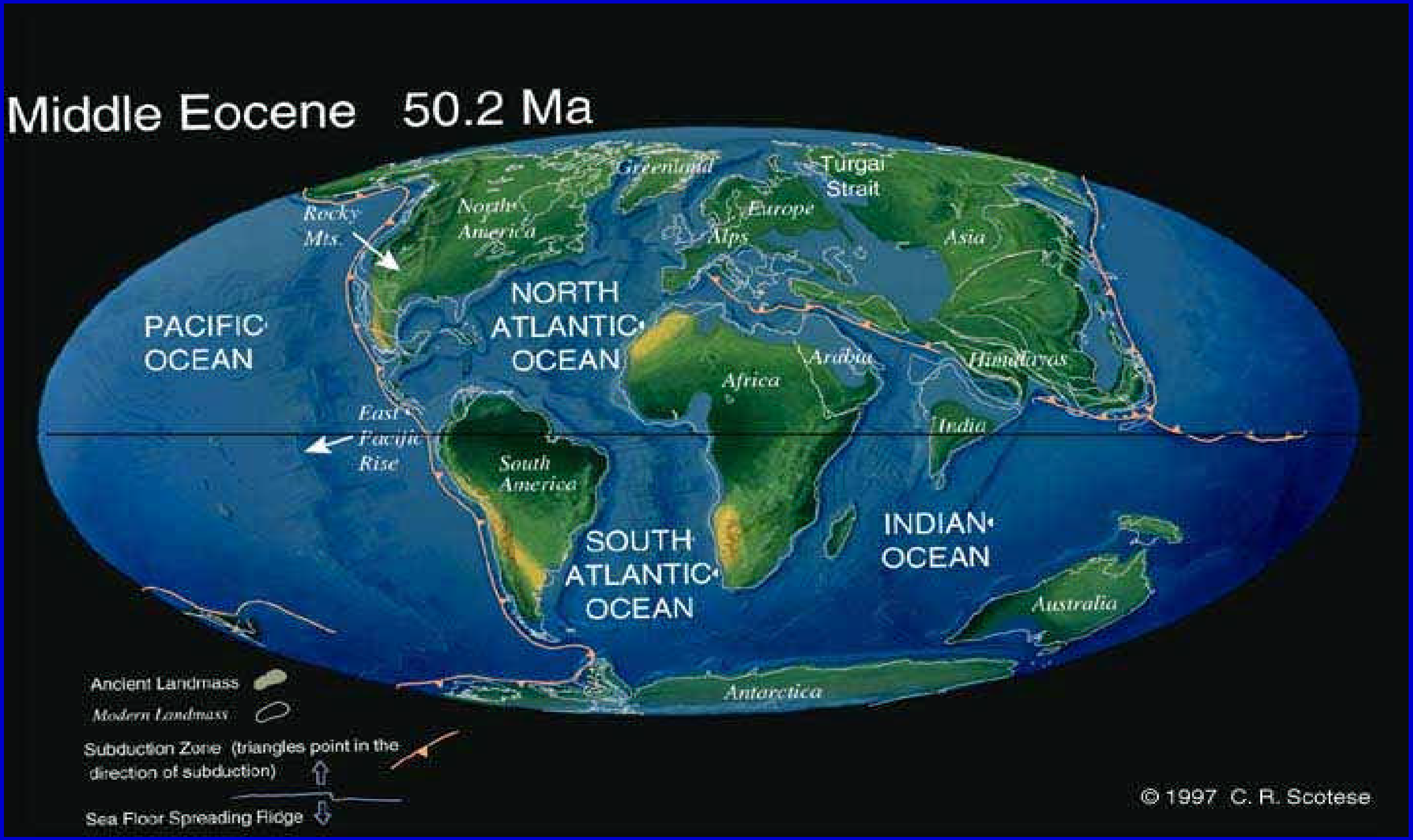
Shallow seaways covered the continents because sea level was 100 - 200 meters higher than today. Higher sea level was due, in part, to the creation of new rifts in the ocean basins that, as discussed previously, displaced water onto the continents. The Cretaceous was a time of rapid sea-floor spreading.

LATEST CRETACEOUS 69.4Ma



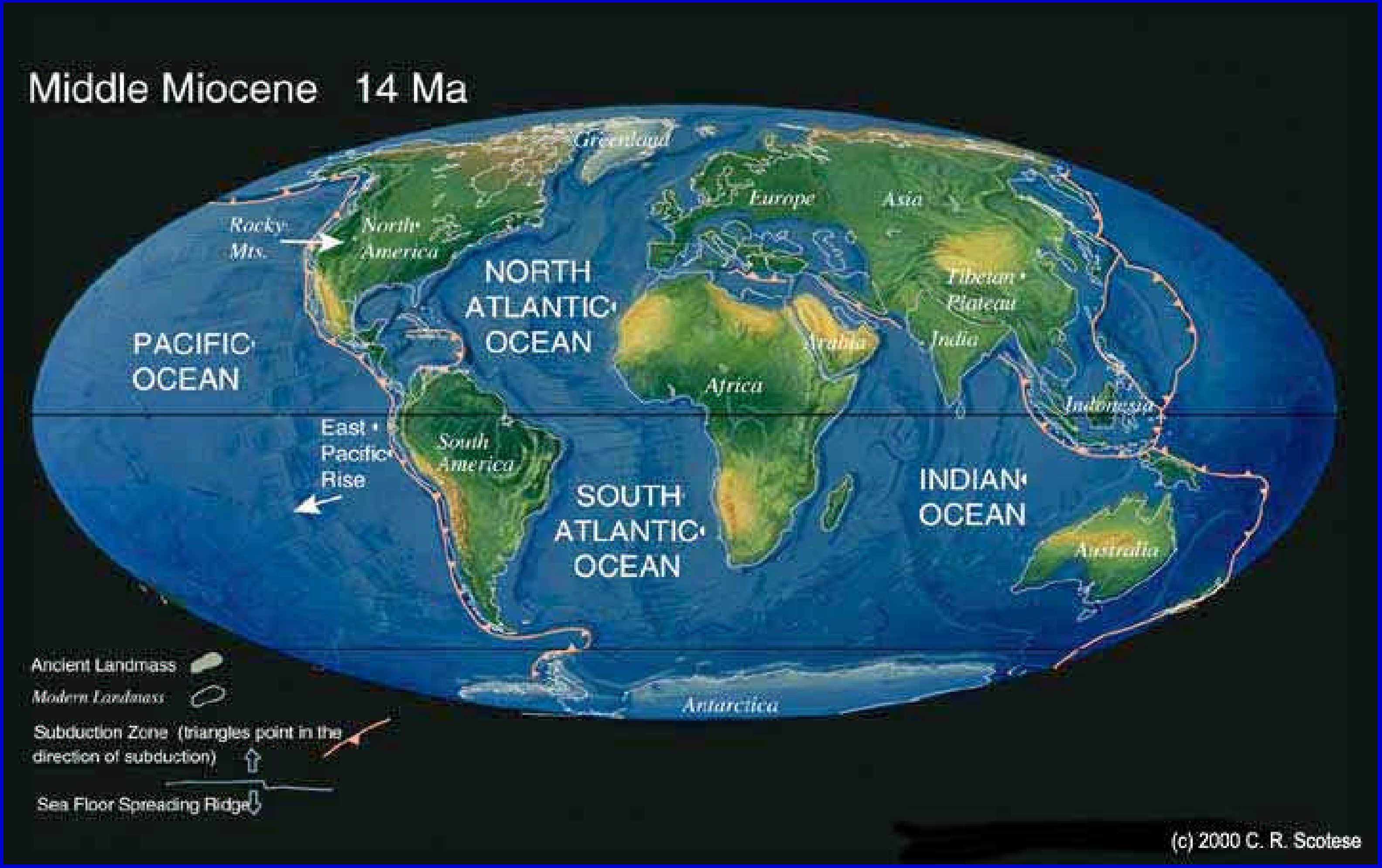
Dinosaurs became extinct at the end of the Cretaceous. This extinction is believed to have been caused by a large meteorite that struck the Earth and caused severe climate changes. The site of the impact is believed to have been in the Gulf of Mexico

MIDDLE EOCENE 50.2 Ma



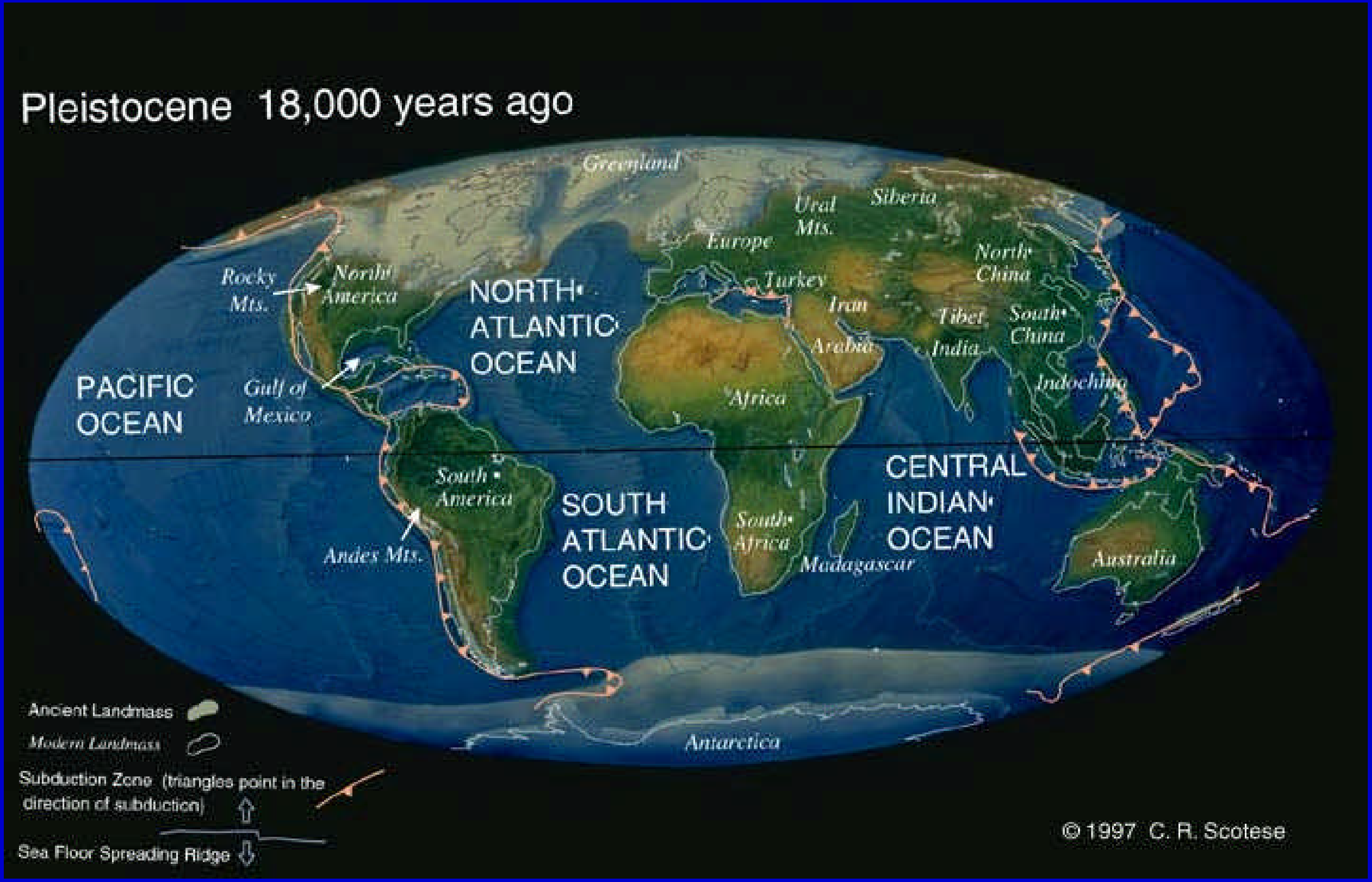
50 - 55 million years ago India began to collide with Asia, forming the Tibetan plateau and the Himalayas. Australia, which separated from Antarctica, began to move rapidly northward.

MIDDLE MIOCENE 14Ma



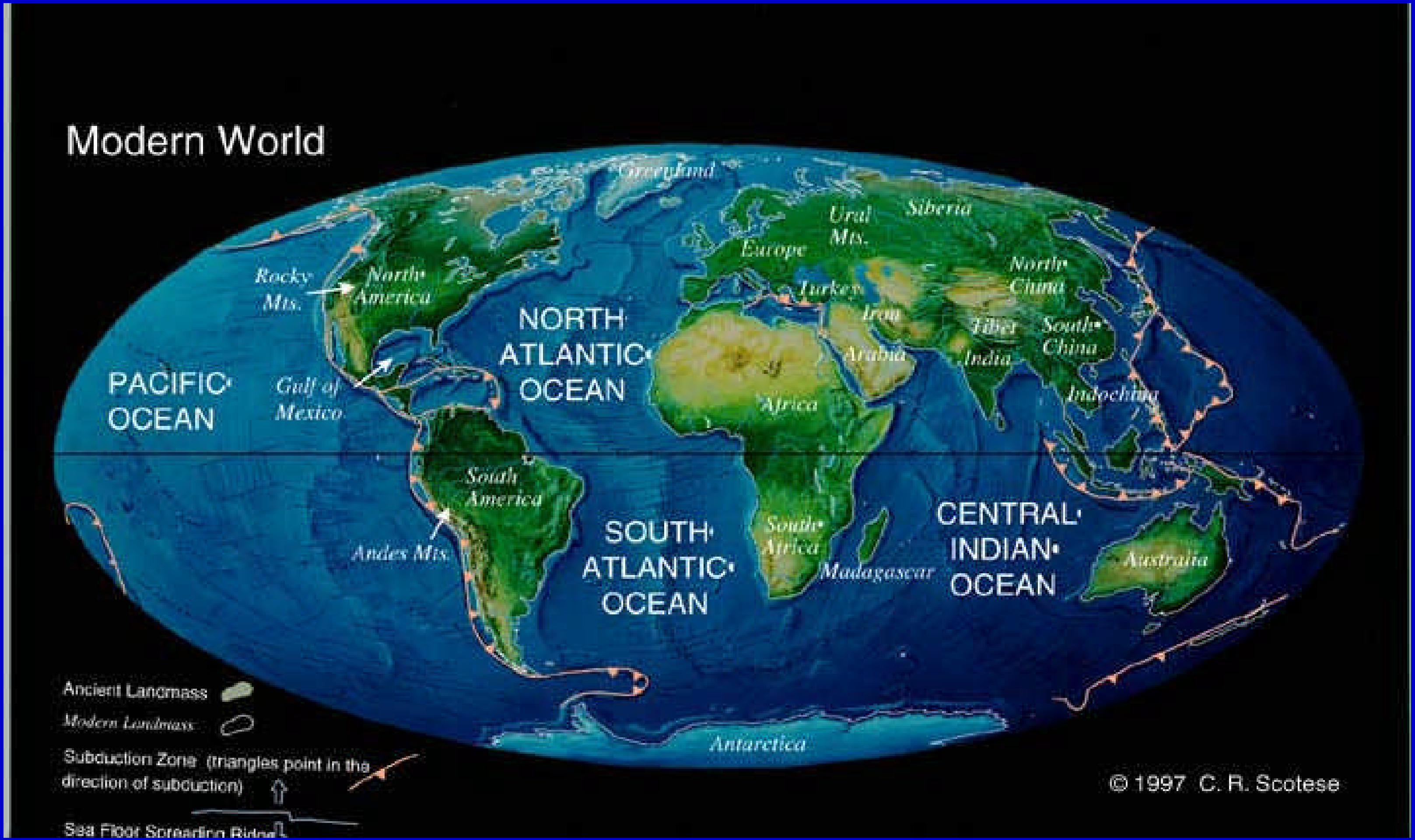
Antarctica was covered by ice and the northern continents were cooling rapidly 20 million years ago. The world had taken on a "modern" look, but notice that Florida and parts of Asia were flooded by the sea.

PLEISTOCENE 18,000 YEARS AGO



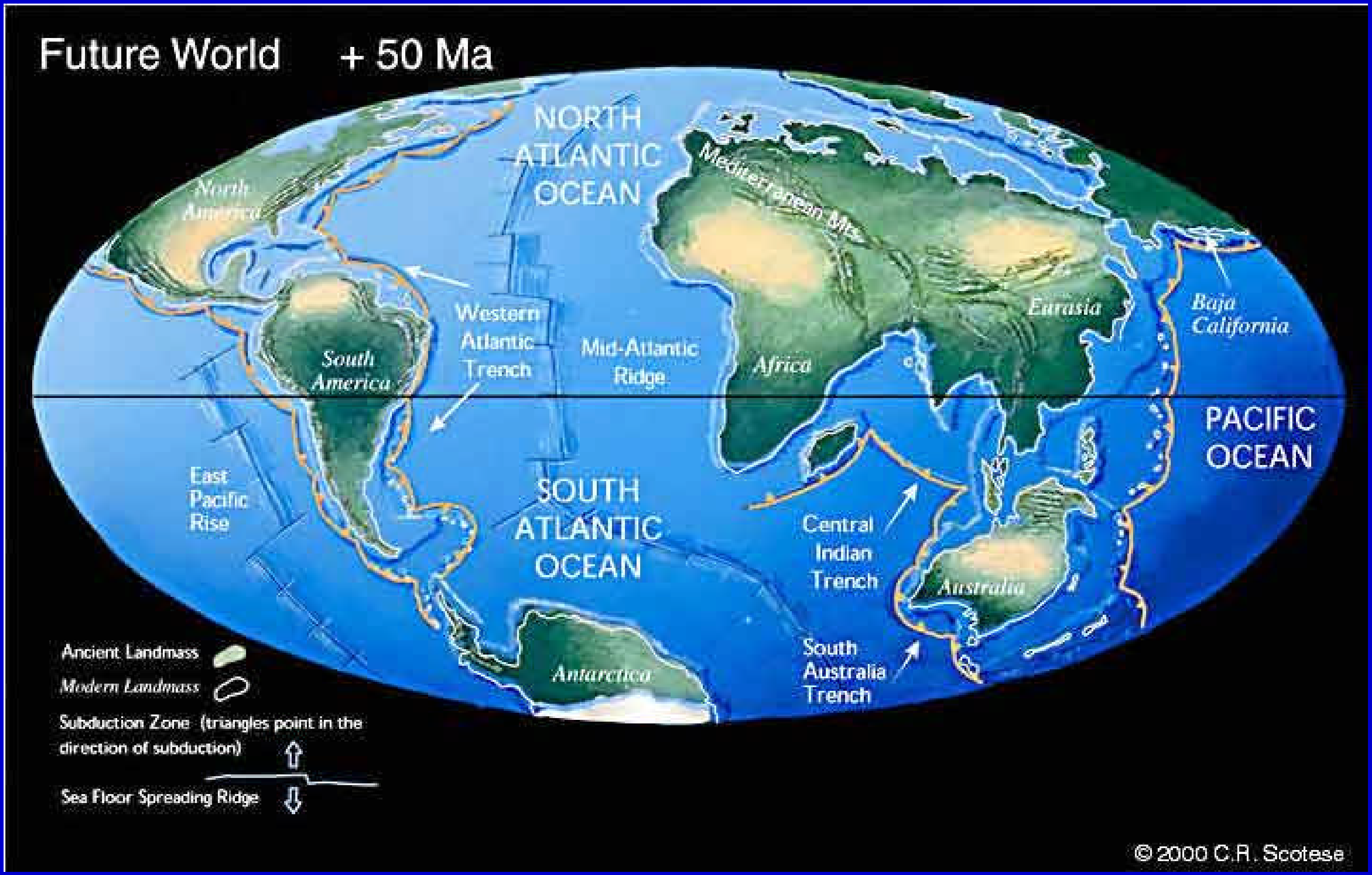
Notice the distribution of the ice sheets in the southern and northern hemispheres and the land bridges across the Bering Strait and Central America, allowing migration of animals from Asia to North America and between North and South America.

MODERN WORLD



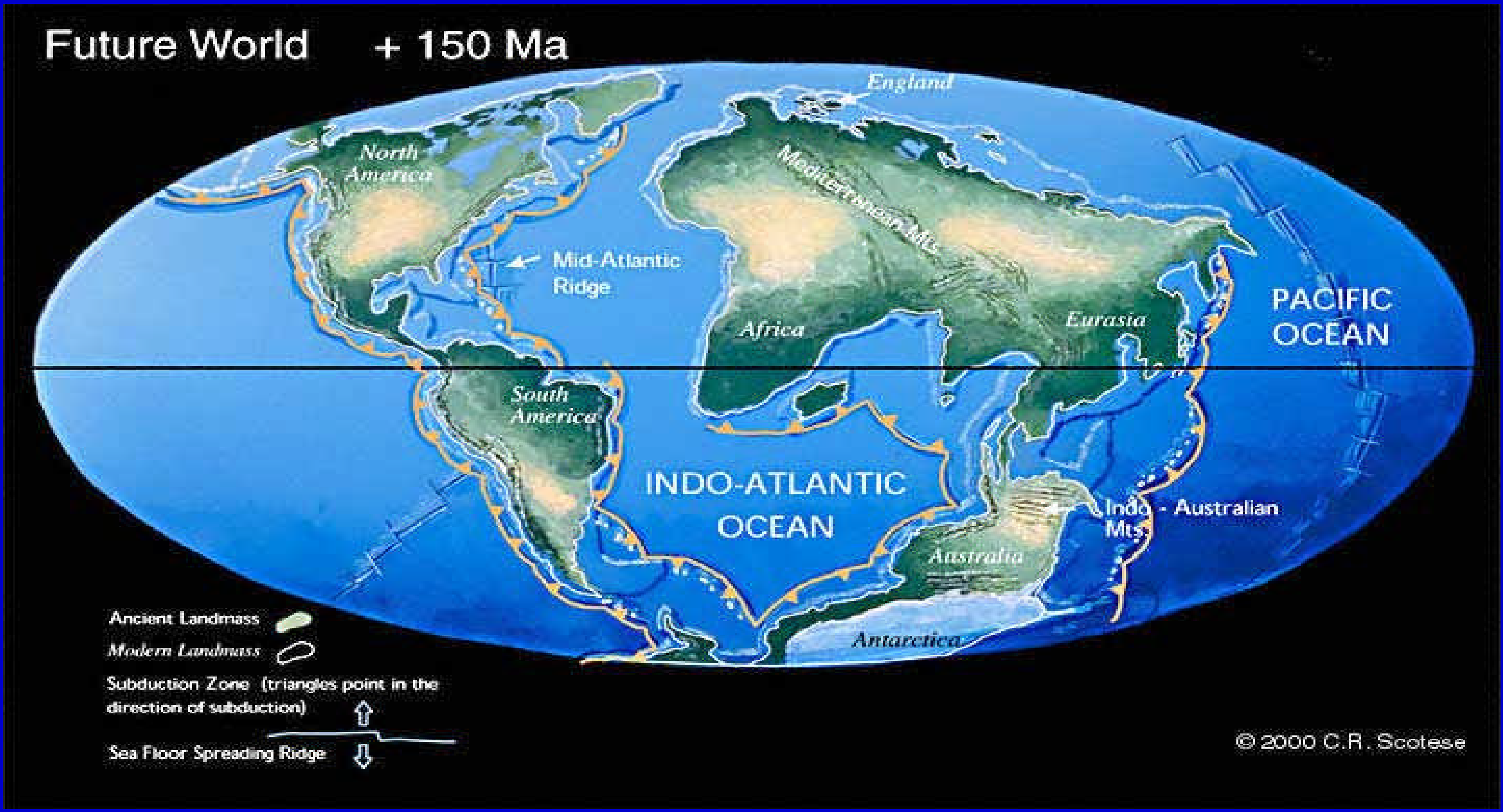
Earth is entering a new phase of continental collision that will ultimately result in the formation of a new supercontinent. Global climate is warming because we are leaving an Ice Age and because we are adding greenhouse gases to the atmosphere.

FUTURE WORLD +50 Ma



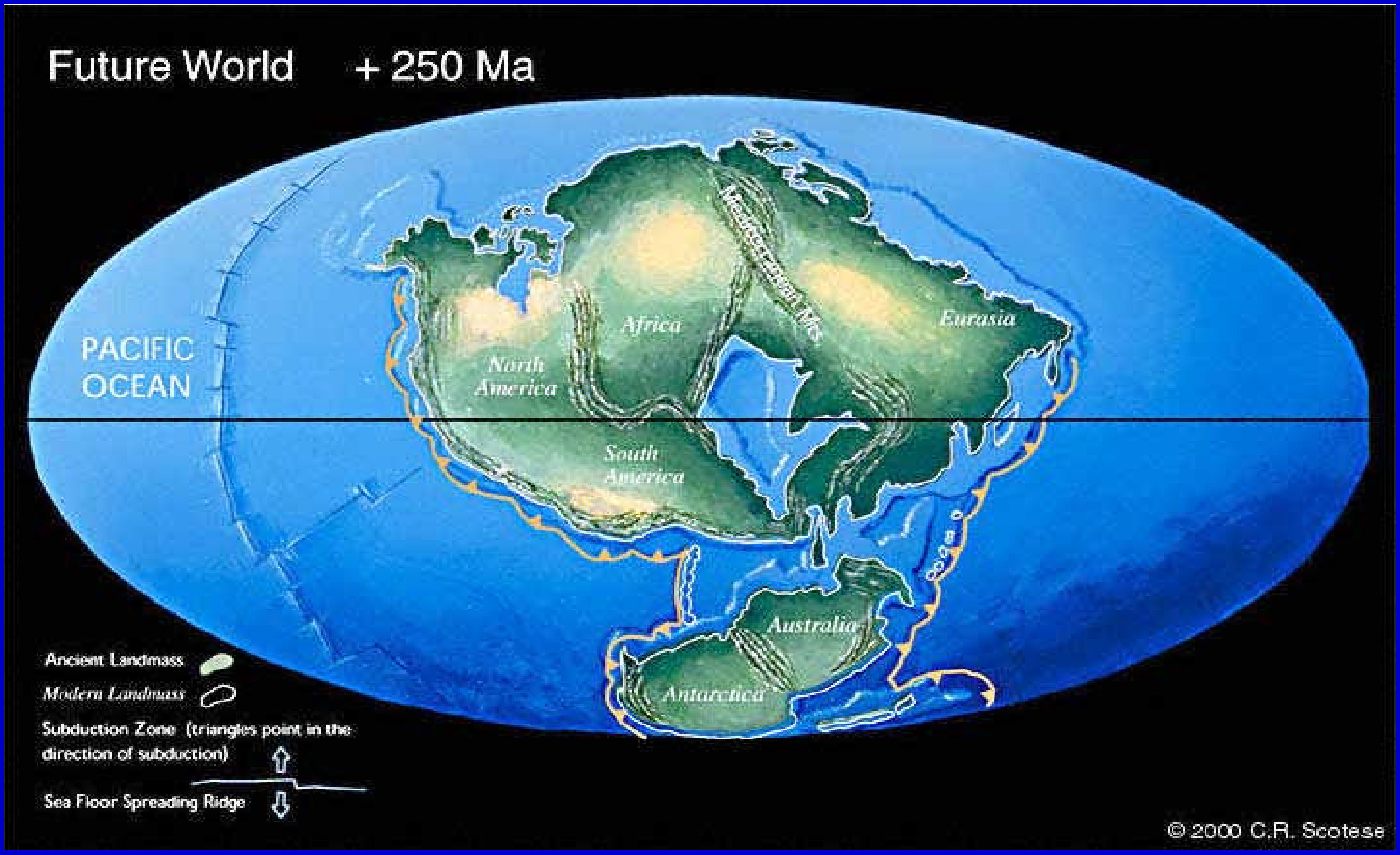
If present-day plate motions continue, the Atlantic will widen, Africa will collide with Europe and close the Mediterranean, Australia will collide with South East Asia, and California will slide northward up the coast to Alaska.

FUTURE WORLD +150Ma



New subduction zones along the eastern coasts of North America and South America begin to consume the ocean floor that separates North America and Africa. About 100 million years from now, the present-day Mid-Atlantic Ridge is subducted and the continents begin to come closer together.

FUTURE WORLD +250Ma



The next Pangea, " floor of the North and South Atlantic beneath eastern North America Pangea Ultima" will form as a result of the subduction of the ocean and South America. This supercontinent will have a small ocean basin trapped at its center.